

ECOCITY WORLD SUMMIT 2021-22
CONFERENCE PROCEEDINGS

FEBRUARY 22-24, 2022
ROTTERDAM, THE NETHERLANDS

ECOCITY WORLD SUMMIT 2021-22 HOSTING PARTNERS

TU Delft and SASBE



Summit Secretariat



Ecocity World Summit is an initiative of California USA-based nonprofit Ecocity Builders.

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ISBN: 978-0-578-77618-7

Letter from Kirstin Miller



Ecocity development combines vision and citizen initiative, where nature, agriculture, and the built environment integrate and thrive.

Ecocity World Summit 2021-22 convened in conjunction with SASBE 2022 – 7th CIB international conference on Smart and Sustainable Built Environments. This edition offered a unique virtual experience for participants around the globe, taking place on 22-24 February 2022, after a postponement due to the global pandemic.

Ecocity 2021-22 catered to innovators and pioneers, engineers and planners, policymakers and administrators, professionals and businesspeople, environmentalists and developers, teachers and students, and artists and designers. The conference focused on related themes of healthy and sustainable cities, towns, and villages – from theory and research to the application and implementation of all things related to the ecological city.

These proceedings organize contributing papers into four chapters under the four pillars of the Ecocity Framework and Standards: i) urban design, buildings, and transportation, ii) bio-geophysical conditions, iii) socio-cultural features, and iv) ecological imperatives.

We also have a supplemental chapter from our Summit hub in Egypt, led by Cairo University.

I'd like to take this opportunity to sincerely thank the conference organizers. In particular, thank you to Nico Tillie and Andy van den Dobbelen at TU Delft. Without your perseverance and leadership, Ecocity 2021-22 would not have been possible.

Finally, thank you to all who attended the Summit and contributed your knowledge to the global ecocity movement. We applaud every one of you. There has never been a more opportune time for ecocities.

Sincerely,

A handwritten signature in cursive script that reads "Kirstin Miller".

Kirstin Miller
Executive Director
Ecocity Builders

Letter from Dr. Nico Tillie and Professor Dr. Andy van den Dobbelsteen



The 14th Ecocity World Summit - URBAN TRANSFORMATIONS FOR NATURE BASED SOLUTIONS - featured a wide range of lectures, workshops and other opportunities to exchange knowledge and ideas to take new steps towards transforming our cities as towards ecocities. Showcasing the latest research and developments in urban design and city transformation practices we sincerely hope - albeit a small step- to have contributed to a better world for our future generations.

As chairs of this 14th edition of the Ecocity World Summit we had to deal with an unprecedented situation involving lockdowns, travel bans, shifting budgets, shifting venues, shifting dates, a shifting reality in which we and our program committee had to be resilient, adaptive, and flexible to the end. This would not have been possible without the unconditional support of Kirstin Miller the executive director of Ecocity Builders as well as all other members of the program committee who at different moments in different ways were crucial in turning this event into a success. Thank you: Rob Roggema, Sahar Attia, Steffen Nijhuis, Cecil Konijndijk, Denise Noslin, André Confiado, Maarten Nijpels, Katharina Hölscher, Russell Galt, Marco Roos, Jip Louwe Kooijmans, Sharon Gil, Bertram de Rooij and Elsa Lefevre.

Also, a special word of thanks to Catherine Kalamidas of Rotterdam Partners who invited me to bid for this conference, thanks to the conference organizers - Kenes Group and our colleagues and staff at our faculty of architecture and built environment at Delft University of Technology (TU Delft).

We are very proud that we were able to host this wonderful 14th edition with a great group of knowledgeable and enthusiastic contributors and visitors. Let us move forward together and meet online or in London 2023.

Yours sincerely,

Dr. Nico Tillie
Section of Landscape Architecture
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Department of Urbanism, Faculty of Architecture and the Built Environment, TU Delft
Chair of the 14th Ecocity World Summit

Professor Dr. Andy van den Dobbelsteen
Sustainability Coordinator TU Delft
Chair of SASBE at the 14th Ecocity World Summit

Letter from Heba Allah Khalil, PhD



Greater Cairo, being the biggest arid city worldwide faces complex challenges fueled by climate change and increased heat stress. As such, hosting a local chapter of the Ecocity World Summit to focus on the issues the city face presented an opportunity that Cairo University gladly seized. The invitation by Ecocity Builders to open the conference and its discussion to much needed local discussions and dialogues is an innovation in conference setups that could expand globally facilitated by a growing familiarity with online tools and communication. Hence a satellite virtual one day conference was organized by Department of Architecture, Faculty of Engineering, Cairo university under the supervision of Prof. Sahar Attia, Prof. Ayman Hassan, Prof. Heba Allah Khalil, and Assoc. Prof. Mennat - Allah El - Hussein.

The organizing committee chose to focus its call for papers on Ecocity 2021 themes that are most relevant to the Cairene context: Healthy City and Resilient city. The conference was an excellent opportunity for professors, scholars, researchers, and students to exchange ideas, agendas, guidelines, and frameworks for Post Covid city practices, with special attention to the two main themes adopted by the satellite conference. The satellite conference received 20 English abstracts and 6 Arabic Abstracts. Another feature of the satellite conference is that it welcomed interventions in the local language; Arabic; to facilitate expand the ecocity discussions among wider audiences. 14 abstracts were accepted for presentation, out of which 9 papers were accepted and published in this proceeding. In addition, a plenary talk about health and the city was given by Dr. Naeema El Gasseer, World Health Organization Representative in Egypt & Head of Mission.

Exploring Horizons of Sustainable Development Post-Covid-19 Era in Egypt presents the investigations and findings that Cairene scholars developed. However, the main takeaway of this body of work is putting health, both physical and mental, central in the research, design, and planning of our spaces, neighbourhoods, and cities.

Heba Allah Khalil, PhD
Professor of Sustainable Urbanism, Cairo University
Organizing Committee Member, Cairo Satellite Conference

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URBAN DESIGN AND TRANSPORTATION

The city is designed and developed with the underlying principle of access by proximity, providing residents with walkable access to open/green spaces, basic urban services, and affordable housing. It demonstrates environmentally friendly transport options and provides walking and transit access to close-by employment.



THE SELECTION OF DISTRICTS REGARDING LOW-CARBON DAILY COMMUTE ACROSS TEHRAN: A SQL-BASED DATA ANALYSIS

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ABSTRACT

Large cities are in constant change due to the dynamism and growing urban population. Such flows of people rely on sound and timely transport systems, resulting in more traffic congestion, air pollution, carbon emissions, infrastructure, and energy consumption. Sustainable solutions and strategies are developed to reduce these burdens and make transportation more sustainable and effective.

This research has considered Tehran as the largest city in Iran in terms of population and size area. The city has grown fast due to mass rural-urban migrations, industrialization, and improper urban development over the past decades. Currently, the city has embedded 22 Municipality Districts across its vast fish-like shape area.

Based on a recent comprehensive annual report published by the Tehran Municipality, we determined the most influential parameters affecting daily commutes across all residential areas located in 22 Districts. A total of 15 variables were defined, such as 'number of the population per area unit' (*Pop_dens*). As an innovative data analysis approach, we employed SQL algorithms to evaluate relationships between these 15 variables and select those with lower-than-mean thresholds. We then crossed each of these variables chosen with daily commutes figures for each District. We could attain several SQL-based queries and determine the best District for offering low-carbon daily commutes. Among all Tehran Districts, District-22 could offer higher scores (6 out of 10) based on queries made for low-carbon daily commutes.

This research revealed a reliable data analysis approach to tackle transport inefficiency and reducing carbon emissions in the cities.

KEYWORDS

SQL; Daily Commute; Low-carbon; Tehran

INTRODUCTION

Urbanization in Iran: Focusing on Tehran

The start of unprecedented modern urbanization in Iran coincided with the exploration of oil fields. During the early years of the twentieth century, oil-driven urbanization was started in southwest Iran and continued at a higher pace, particularly in Tehran. Earlier, Tehran's expansion was not uniform temporally and spatially as it depended on the will and even mood of the autocrats. "Writers had noted Tehran's narrow, crooked streets, which were not used for wheeled transport, as wheeled transport was not commonly used in Iran in those times" [1, p. 325].

This research has made a case for Tehran as the largest city in Iran regarding population and size area. The city has grown fast due to mass rural-urban migrations, industrialization, and improper urban development over the past decades. Tehran is a 200-year-old Capital city with a unique background. Such uniqueness can be attributed to the fact that Tehran has grown from a small and insignificant political and economic city to the current most populated city in Iran. It has experienced three specific migration movements over the past half a century: First, during the period 1956-66 when it became a leading destination (38%) of immigrants [2]. Two towns and 132 villages were absorbed to expand Tehran to accommodate this growing population [3]. Second, during 1966-76, rural-urban migration led to growing squatter settlements in major cities, especially Tehran [4]. A 22% increase in the rural-urban migration rate (a total of 3.5 million) was recorded for this period [5]. Tehran's annual population growth was estimated at 6.6% in 1966-1969 [6]. Third, during and after the Iran-Iraq war (the 1980s), the mayhem after the destructive war and pull factors in large cities (e.g., improved infrastructure and services) attracted more population. In 2001, Iran's urban population surpassed 50% of the total population [7]. Iran's urbanization has followed the world's experiences from 1950 until 1980 due to intense industrialization and urbanization [8].

Over the past 200 years, Tehran has been enlarged extensively [9]. Currently, Tehran has close to 9 million population (the most populated city in Iran) and close to 1335 km² size area. The city has enclosed 22 Municipality Districts (D1 to D22 in our research) across its vast fish-like shape area with 550 km of highways and main roads. In addition to a growing population and extensive land use challenges, Tehran's valley-like topography and dry climate can also be mentioned.

'Low-carbon Commute' Concept

Cities are regarded as the sites of high consumption of energy [10]. Urban areas were responsible for 71% of global energy-related carbon emissions in 2010 (World Energy Outlook cited by [10]). CO₂ emissions from heavy-duty vehicles (trucks and buses) have increased on average 2.2% annually since 2000 [11]. The latest figure of CO₂ emissions from trucks reached 1856 Mt CO₂ in 2018 [11]. Average emissions of small cars stand at 42 gCO₂/p/km, SUVs as 55 gCO₂/p/km and trains at 14 gCO₂/p/km (cited by [12]).

Various countries have proposed a diverse range of binding and non-binding commitments to improve the efficiency of average fuel consumption of new cars by 2030 [11]. The term 'commute' has become 'shorthand for the daily journey between work and home' (Lyons & Chatterjee cited by [10]). In most cities, the private car remains the dominant mode of everyday mobility with implications for sustainability and climate change and local air quality, congestion, social exclusion and isolation, and public health and well-being [10].

MATERIALS AND METHODS

Data

Tehran's research case is enumerated as a city with low average precipitation and a high carbon footprint [8]. In this research, we used a comprehensive annual report published by Tehran Municipality in 2019 [13]. This 598-page report in the Persian language illustrates very detailed and updated data on nearly every aspect of the socio-economic issues of Tehran, from the population to transport to the economy to crime. The report encompasses other associated regions based on their urban management definitions, but we will focus only on 22 Districts in this research.

We extracted data such as population, number of public cars, daily trips, etc. and called them as 'variable'. A total of 15 variables were defined, such as 'number of the population per area unit' (Pop_dens) (Table 1). They were the most influential variables affecting daily commutes across all residential areas located in 22 Districts. We carefully selected those data which were more relevant to our research purpose. We entered these data into a spreadsheet for further analysis.

SQL Algorithms

In a study to analyse geographical patterns of traffic congestion in Beijing, Zhao and Hu [14] used SQL algorithms for data management and basic statistical calculations. In our research, we employed SQL algorithms to evaluate relationships between these 15 variables (Table 1). We then crossed each of these variables chosen with daily commutes figures for each District. We could attain several SQL-based queries and determine the best District for offering low-carbon daily commutes.

Table 1. Descriptive and statistical features of SQL-based variables defined in this research

| Row | Variable code in SQL | Variable | Description | Unit (per District) | Min | Max | Mean | SD |
|-----|----------------------|--|---|---------------------|--------|--------|-----------|---------|
| 1 | <i>Pop_dens</i> | Population density | Number of population per area unit | ha | 34 | 412 | 184.09 | 102.25 |
| 2 | <i>Fire_inc</i> | Fire | Number of reported fire incidents | year | 229 | 1859 | 921.77 | 473.69 |
| 3 | <i>Per_Cap_GS</i> | Greenery spaces | Area of greenery spaces per capita | m ² | 2.58 | 58.67 | 16.44 | 13.25 |
| 4 | <i>Literacy</i> | Residents' literacy | Literacy rate of residents | % | 86 | 99 | 90.54 | 3.56 |
| 5 | <i>Complaints</i> | Residents' complaints | Number of complaining calls | year | 717 | 3056 | 1422 | 706.01 |
| 6 | <i>Dev_units</i> | Newly built units | Number of newly built units | year | 2538 | 15764 | 7984.33 | 3320.23 |
| 7 | <i>Over220</i> | Size area of units (residents of such units may possess more than one vehicle) | Number of units with an area over 220 m ² | year | 258 | 8110 | 2798.72 | 2507.21 |
| 8 | <i>150_220</i> | Size area of units (residents of such units may possess more than one vehicle) | Number of units with an area between 150 and 220 m ² | - | 410 | 4231 | 1849.86 | 993.22 |
| 9 | <i>91_150</i> | Size area of units | Number of units with an area between 91 and 150 m ² | - | 532 | 4433 | 1899.27 | 998.25 |
| 10 | <i>75_90</i> | Size area of units | Number of units with an area between 75 and 90 m ² | - | 10 | 605 | 297 | 172.73 |
| 11 | <i>Less75</i> | Size area of units | Number of units with an area less than 75 m ² | - | 56 | 1383 | 555.04 | 443.14 |
| 12 | <i>Old_fab</i> | Age of residential areas | Area of old zones | ha | 1 | 593 | 148.68 | 157.33 |
| 13 | <i>Dail_Tra</i> | Daily commute | Number of daily commutes | Person/year | 120080 | 967331 | 419650.72 | 221141 |
| 14 | <i>Park_Cap</i> | Car parking | Number of car park capacities | vehicle | 821 | 19491 | 4991.59 | 4364.53 |
| 15 | <i>Taxi</i> | Taxi | Number of taxis with fixed route | vehicle | 0 | 2016 | 862.36 | 769.05 |

RESULTS

Correlation Among Variables

We analysed selected variables with lower-than-mean thresholds (defined in Table 1) to illustrate their correlations with daily commute figures (Dail-tra). As shown in Table 2, a high correlation was found between daily commute with variables such as fire, complaints, size area of residential areas, and the number of taxis.

Table 2. Pearson Correlation between daily commute and selected variables

| Variable | Dail_tra | Variable | Dail_tra |
|------------|----------|----------|----------|
| Pop_dens | 0.07 | 150_220 | 0.76 |
| Fire_inc | 0.71 | 91_150 | 0.22 |
| Per_Cap_GS | -0.13 | 75_90 | -0.15 |
| Literacy | 0.48 | Less75 | -0.06 |
| Complaints | 0.93 | Old_fab | -0.15 |
| Dev_units | 0.86 | Park_Cap | -0.30 |
| Over220 | 0.76 | Taxi | 0.56 |

Our Criteria versus Global Criteria

Based on the correlations (Table 2), we came up with a narrowed number of 10 criteria which showed higher correlations to define low-carbon Districts. Then, in an attempt to compare our selected criteria with other ones at the global level, we considered the criteria proposed by [15]. They assessed sustainability for urban mobility projects and proposed the inclusive criteria list extracted from 14 research articles. Accordingly, we considered variables such as population density, fire, greenery spaces, residential's complaints, age of residential areas (old fabric), parking spaces, taxis, newly developed units, and large-size units (Table 3). Four criteria were new to our research only.

Table 3. Criteria used in this research versus criteria at the global level

| Row | Urban variables in this research | Description | Our criteria matched by [15] |
|-----|----------------------------------|--|--|
| 1 | Population density | Number of population per area unit | Equity in the use of public space |
| 2 | Fire | Number of reported fire incidents | <i>This research</i> |
| 3 | Greenery spaces | Area of greenery spaces per capita | Quality of life |
| 4 | Residents' complaints | Number of complaining calls | Public participation in decision making |
| 5 | Age of buildings | Age of residential areas | <i>This research</i> |
| 6 | Parking spaces | Number of car park capacities | Control and monitoring of traffic |
| 7 | Taxis | Taxis | Equity in the use of public transportation |
| 8 | Newly developed units | Number of newly built units | <i>This research</i> |
| 9 | Size area of units | Number of units with an area between 91 and 150 m ² | <i>This research</i> |
| 10 | | Number of units with an area between 75 and 90 m ² | |

Choosing the Best District

Table 4 describes the SQL-based Expression, logics of the selection of variables and the result (Selected District). Among all Tehran Districts, District-22 could offer higher scores (6 out of 10) based on queries made for low-carbon daily commutes.

Table 4. Relationship between daily travel and selected urban variables

| Urban variables | SQL-based Expression | Logic | Selected District |
|-----------------------|--|--|-------------------|
| Population density | DT versus population density (where population density \leq 184.09) | Lower population density correlate with less daily commute | D22 |
| Fire | DT versus fire (where fire incidents \leq 921.77) | Lower fire incidents correlate with less daily commute | D22 |
| Greenery spaces | DT versus greenery spaces (where greenery spaces \geq 16.44) | Higher greenery spaces correlate with less daily commute | D22 |
| Residents' complaints | DT versus residents' complaints (where complaints \leq 1422) | Lower resident complaints correlate with less daily commute | D22 |
| Age of buildings | DT versus old fabric (where old fabric area \leq 148.68) | Lower old fabric buildings correlate with less daily commute | D22 |
| Car Parking | DT versus car parking spaces (where greenery spaces \geq 4991.59) | Higher car parking correlate with less daily commute | D22 |
| Taxi | DT versus taxi (where taxi \geq 862.36) | Higher taxi numbers correlate with less daily commute | - |
| Newly developed units | DT versus new developed units (where new developed units \leq 2538) | Higher number of new units correlate with less daily commute | - |
| Size area of units | DT versus units with an area over 220 m ² (where units \geq 2798.72) | Larger units correlate with higher daily commute | - |
| | DT versus units with an area between 150 and 220 m ² (where units \geq 1849.86) | Larger units correlate with higher daily commute | - |

DISCUSSION

Across the globe, large cities face rapid urbanisation, urban renewal, immigration and economic cycles [16]. Also, they are in constant changes and modifications. These artificial alterations are inevitable due to their dynamism and growing urban population [12]. A prediction of a 6.4 billion urban population by 2050 [16] is a reminder of such colossal issues ahead of us.

This growing population in large cities need matching infrastructure and services, including sound and timely transport systems. Municipalities have destructed greenery spaces to develop built-up areas and paved paths as required for expanding commuting spaces for private and public vehicles. The result has been more traffic congestions, air pollution, carbon emissions, and energy consumptions in almost all large cities, especially in developing countries (e.g., Beijing: [14]; São Paulo: [17]).

Contemporary Tehran is no exception and faces such challenges. Tehran Municipality has undergone unprecedented alterations in various aspects, from developing highways to expanding greenery open spaces to improving safety measures. However, due to the growing population and limited open spaces, challenges are mounting and as such frequent public calls have asked to relocate the Capital over the past decades [9].

One of the improved and modernised aspects of contemporary Tehran has been its overall transport system. Since decades ago, the central Tehran streets have been designated as restricted zones during the working daytime for all vehicles except registered cars and taxis. It has been supposed to reduce traffic jams and air pollution. Tehran transport system includes public buses and subway and private taxis, cars and motorcycles. The Bus Rapid Transit (BRT) Lines have been developed to accelerate bus commuting speed for encouraging people to use. The Uber-like taxi services are growing in numbers, though their time and cost efficiencies are also affected by heavy street traffic jams. Tehran Municipality has recently invested in expanding special cycle lanes for cycling, but public attention has been insignificant so far, and cycling is still a luxury commute system. The number of electric cars in Tehran is insignificant even though the number of private vehicles has increased dramatically. Since 2010, the national government has cut energy subsidies (including car fuels) to distribute the oil revenues more evenly among the Iranian population, especially low-income families. As a result, the price of car fuel has skyrocketed. However, even such a high price has not discouraged people from using private lone-driver cars. Tehran lacks free spaces for allocating and developing car-parking, and thus (pre-paid) street-parking is widely used. This driving attitude has compounded traffic congestion and

increased commuting irregularities in the streets. Motorcycles have become a cheap and efficient way for the poor to overcome traffic jams for large distances by ignoring civil laws and rights (e.g., passing through pedestrian paths).

Moreover, in addition to those commuters living inside the city, rising commuters are coming from the Tehran suburbs. These are generally low-income families living in Tehran's outskirts, and by large, they utilize subway and old bus fleets to come to Tehran for low-paid jobs.

Air pollution has become a constant problem in Tehran, especially since the early 2000s. Several factors have contributed to this air pollution, including raising the number of private cars and motorcycles and raising the age of public fleets. Lone drivers are criticized as one of the leading air polluters in Tehran. In the early year of 2021, Tehran's air pollution was exacerbated due to the high consumption of low-quality, high-sulfur fuel oil known as mazut [18]. Power plants use this oil by-product during the winter season. At that time, air pollution and frequent blackouts were attributed to the very high electricity usage of Bitcoin miners [18].

Our comparison showed that we had defined four new criteria in our research in addition to what has been proposed by [15]. Here, we provide a logical foundation for these four criteria:

Fire: We could not find reasons why fire showed a high correlation with our research's daily commute.

Age of buildings: This criterion that showed a high correlation could be that old-age buildings typically need more housing refurbishments and repairs. From the Iranian cultural viewpoint, such buildings are owned by old couples with extended family members. Thus, these old buildings are highly likely to host larger invitees and high daily commute for parties and get-togethers.

Newly developed units: Such new developments in Iran encompass massive daily commutes. Generally, people visit such buildings for buying or renting. New residents of such buildings are young couples with high daily commutes to work, leisure, education, etc. All of these matters necessitate frequent daily commutes.

Size area of units: A new trend of middle-class families in Iran have emerged as they buy larger houses and several private cars. Those Districts that encompass such types of new wealthy families suffer from their high share of cars per family.

Based on our criteria defined in the research, it was shown that only one District (out of 22 districts) was in a better position for low-carbon transport options. This District is a newly developed Tehran District and located in west Tehran. Distinctively, this District has been expanded to respond to housing demands from the civic services (e.g., personnel of public organizations). It has brought a growing number of populations from inside and outside Tehran. Another issue is that District-22 is far from most major educational, administrative and health services, and thus, growing populations have to commute long distances as there are no subway or bus lines. District-22 has a very low population density and less daily commute, but it is unclear whether this low population density remains untouched for the long term.

CONCLUSION

This research revealed a reliable data analysis approach using SQL algorithms to tackle transport inefficiency and reducing carbon emissions in one of the Tehran Districts (D-22). Tehran Municipality must plan earlier to avoid mistakes and challenges of other Districts. District-22 encompasses large open spaces suitable for developing low-carbon options such as electric monorails, electric buses, solar street lighting, etc.

Over the past decades, asymmetrical and unplanned expansions of Tehran have caused rising social and economic difficulties. The city's infrastructure has never been satisfactory, leading to rising public and private transport and commuting issues. Elsewhere, it has been shown that the quality of life across 22 districts of Tehran is asymmetrical (19). Like many other large cities and Capitals across the world, Tehran has a long way to claim to attain urban sustainability. Given the mentioned considerations and bottlenecks, Tehran's low-carbon transport system remains an unattainable and luxury option for years to come.

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SPACE FOR CITIES: SATELLITE APPLICATIONS ENHANCING QUALITY OF LIFE IN URBAN AREAS

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ABSTRACT

As growing urbanisation is challenging the way we live and interact with the natural environment, Eurisy launched an initiative to promote the use of satellite applications to make our cities healthier, cleaner, safer, and more efficient. The initiative aims to foster the exchange of expertise and know-how among city managers, SMEs and stakeholders; identify challenges to access and use satellite data and signals; and make recommendations to service providers, space agencies and policy-makers on how to facilitate the use of such data in cities.

Satellite imagery is already employed in cities, e.g. to identify urban heat islands or to make predictions about the impact of different traffic scenarios on air quality. Satellite navigation is crucial in providing real-time information on public transport and numerous apps rely today on satellite navigation signals, e.g. to help persons with disabilities in their daily movements. Satellite communication is also used in cities, e.g. to connect rescue teams when other connections are down, or to perform health checks in public spaces.

Despite several satellite-based services have already proved their added-value in fostering cities' efficiency, resilience and sustainability, there is still a lack of awareness among public administrations about the existence of such services, and in particular about the use of satellite Earth observation. This highlights the need to better communicate about the existence of satellite applications and their potential uses, not only to audiences with an interest towards ICTs, but also to the general public and to local administrations, avoiding technical jargon.

KEYWORDS

Earth observation; Satellite navigation; Satellite communication; Satellite applications; Space; ICT; Geographic Information Systems

INTRODUCTION

This paper presents some of the findings of the Eurisy's Space for Cities initiative, aimed at exploring the use of satellite applications in cities and at fostering the development of applications more and more adapted to the needs of city managers. Within this initiative, Eurisy recorded success stories from cities, organised events targeting city representatives, and reported about good practices and challenges in various international forums.

EURISY

Eurisy is a European non-profit association of space agencies, founded in 1989 and mandated to connect space and society. The mission of Eurisy is to make the potential of satellite applications widely known and to foster their take up by civil society, so that the investments made in the space domain result into concrete benefits for society.

Eurisy works around thematic areas, including one especially dedicated to cities. As growing urbanisation is challenging the way we live and interact with the natural environment, in 2018, Eurisy launched an initiative called "Space for Cities" aimed at exploring the use of satellite applications in cities and at fostering the development of applications more and more adapted to the needs of city managers.

The specific goals of the Space for Cities initiative are to:

- Highlight success stories from cities relying on innovative satellite-based services.
- Foster the exchange of expertise and know-how among city managers, SMEs and stakeholders.
- Identify challenges faced by local administrations and SMEs to access and use satellite data and signals.
- Assess the needs of local administrations for which satellite-based services can contribute to the solution.
- Make recommendations to service providers, space agencies and stakeholders on how to facilitate the use of satellite-based services at the city level.

THE SPACE FOR CITIES EURISY INITIATIVE

In 2015, Eurisy implemented a Survey for public administrations using satellite-based services. Out of the replies analysed, 18% were submitted by local authorities. The results of the survey [1] suggest that local authorities might need more support than regional and national administrations to use satellite services.

Indeed, responses show that national administrations have been using satellite-based services before regional and local authorities, although this trend has decreased over time. Moreover, considering previous knowledge of satellite applications, it seems that public managers at the local level have been less prepared to use these tools than their colleagues at the national and regional levels.

Surveyed local authorities seem to also have been less involved in demonstration projects than their peers at the national and regional levels. Almost half of the respondent national authorities and 38% of the regional administrations have been able to profit from demonstration projects. In contrast, only 26% of responding local authorities reported to have accessed such schemes.

Finally, respondent local authorities declared to have had less access to data or expertise free of charge to implement and operate satellite-based services than regional and national authorities.

Satellite Applications for Safe and Resilient Cities



Fig. 1 List of satellite applications for safe and resilient cities. © Eurisy

The concentration of human activities in cities caused an important reduction of green areas within and around human settlements, which makes cities much more vulnerable to climate change and natural disasters.

Satellite-based services have already proved their added-value in improving the resilience of urban areas to natural disasters. Indeed, satellites provide information that can be useful to better prevent and monitor the impacts of natural hazards, such as **floods**, on urban settlements.

Weather forecast is today mainly based on satellite information, which allows to foresee hazards and to adapt the **urban infrastructure** accordingly. Satellite imagery allows city managers to monitor the vegetation status along watercourses which might overflow in case of heavy rains; they also allow to evaluate **slope risks** and to monitor **soil sinking** with centimetre accuracy.

Furthermore, satellites can improve the capacities of **rescue teams**, allowing for precise coordination thanks to real-time geolocation, and they can ensure connectivity in case other connections are down. Finally, satellite-based maps are today largely used to generate **post-disaster maps** for a better planning of interventions.

International mechanisms, such as the International Charter “Space and Major Disasters” and the Copernicus Emergency Management Service are already available to local and regional managers to better face such situations.

Satellites also provide innovative means to enhance security in cities. Many local administrations are already using data based on satellite navigation to study **crime patterns** and to implement **preventive security measures** according to residents’ movements. At the same time, satellite navigation is allowing local police to process **infringements** more efficiently, while saving red tape.

According to the International Ecocity Framework and Standards (IEFS), in a sustainable urban settlement “soils within the city and soils associated with the city’s economy, function, and operations meet their ranges of healthy ecosystem functions as appropriate to their types and environments; fertility is maintained or improved” [2].

The soil allows for life on Earth: it provides a habitat for plants, allows us to produce food, and it is essential for the infiltration and cleansing of water, for microclimate regulation and for providing protection against flooding. However, particularly in urban areas, **soil is being sealed off with increasing housing and infrastructure.**

Satellite imagery offers very precise information on the degree of soil sealing. Earth Observation has allowed scientists to map soil sealing at neighbourhood and building levels in several European cities. Using satellite imagery, scientists could prove that temperatures in cities' green areas are much lower than in highly sealed built-up areas. They were also able to find correlations between soil sealing and floods, since sealing prevents water from infiltrating the soil. This means that soil sealing is likely to exacerbate the effects of heat waves in cities.

Satellites can provide city managers with the sort of reliable and comparable information needed to better plan and manage the urban space by boosting urban green.

Satellite Applications for Healthy and Inclusive Cities



Fig. 2 List of satellite applications for healthy and inclusive cities. © Eurisy

Sustainable cities are concerned with the health and happiness of their inhabitants. Policies based on the integrated urban development approach aim at enhancing the economic growth of cities, while respecting the environment and increasing residents' satisfaction with their lives. Indeed, if the effects of pollution, exclusion and inequalities are more severely felt in cities, it is also in cities that the most innovative solutions can be deployed.

Satellite imagery offers data about **air quality** (i.e., temperature, pollution, presence of pollens and other allergenic substances). This information can help prevent and manage respiratory illnesses. Indeed, in some cities, information on air quality is sent directly on residents' smartphones or is showcased on local television channels.

A sustainable city is also one in which people with **disabilities and the elderly** are provided with opportunities to move freely and have a fulfilling life. Satellite navigation is already embedded in online portals and smartphone apps which provide guidance to people with impaired mobility, and it is integrated in systems allowing autonomous healthcare. Satnav also supports hospitals and emergency services, by enabling them for increased coordination and response.

An integrated urban development requires policies which not only shape the urban infrastructure and services, but also residents' culture and behaviour. In a sustainable city, local authorities promote transparent flows of information and make sure that residents are involved in the design and implementation of local policies.

Satellite services can support engagement in cities. For instance, satellite navigation is already embedded in apps allowing residents to give feedback to their city administrations on different issues, such as damage to the city infrastructure. Satellite imagery is also integrated into geographic information systems (GIS) offering information on the urban environment, assets, and policies.

Cities are ecosystems with their very specific culture. Local historical, natural, and intangible heritage must be protected and promoted, not only for ethical reasons, but also to stimulate the local economy.

Satellite imagery offers precious information on the position and status of archaeological remains, helps monitoring historical buildings and landscapes and provides a layer for augmented reality apps and games. Satellite navigation is instead widely embedded in tourist apps offering information on cities' attractions and events or in geolocated outdoor serious games.

Satellite Applications for Clean Cities



Fig. 3 List of satellite applications for clean cities. © Eurisy

In sustainable cities, patterns of production and consumption shall be conceived to have a minimum impact on the environment. This includes ensuring that emissions do not affect the quality of the air within the city or in the atmosphere, that the soil status and fertility are not endangered, that water sources are healthy, and that the energy consumed and produced does not exacerbate the effects of climate change. Resources should be sourced, distributed and consumed without affecting human health or ecosystems, and — where possible — recycled and reallocated according to the principles of circular economy [2].

According to the World Health Organisation [3], **today pollution represents a greater threat than Ebola and HIV** and is worldwide responsible for one in four deaths among children aged under five. The EU has developed standards and instruments to ensure good air quality by tackling a wide range of pollution sources such as **urban traffic, domestic heating, power plants and industrial activities**. A Partnership on Air Quality has also been created under the Urban Agenda for Europe.

Satellite imagery is today widely employed to provide meteorological information. But that is not all. Earth observation data allows for the measurement and monitoring of air temperature and composition and is used to make predictions on the movements of pollutants in the air. It is also employed to identify urban heat islands (spots in which temperatures are more elevated than in the rest of the city) and to create models to test the effects of different traffic scenarios on air quality.

The Copernicus Atmosphere Monitoring Service uses a comprehensive global monitoring and forecasting system that estimates the state of the atmosphere and that can be used to make air quality predictions in Europe and in the main European cities.

According to the 2015 Trends in Global CO₂ Emissions [4] published by the Netherlands Environmental Assessment Agency and the European Commission's Joint Research Centre, in 2014 CO₂ emissions did not grow and primary energy consumption decreased, as compared to the previous year, for the first time since 1998. This shift is being made possible thanks to the progressive development of **renewable energy sources** such as hydropower, solar energy, wind power and biofuels. These important changes in the energy sector have been emphasised also through the establishment of a new EU energy strategy and policy, aiming at mitigating the effects of climate change.

This trend shows that economic growth does not have to rely on fossil fuel combustion and that energy consumption can be optimised instead of being increased. Many European cities have demonstrated their commitment to reducing their carbon emissions by at least 40% by 2030 by joining the Covenant of Mayors for climate and energy.

Satellite applications can support city administrations re-thinking the management of natural resources by providing additional tools to optimise energy consumption, and to enable the use of renewable and green energies. This is demonstrated by the several operational cases in which satellite services are used to foresee the potential of photovoltaic plants, to support smart grids and to monitor wind and hydropower systems remotely.

The research on green energies is still far from being concluded. Satellites are expected to play an increasing role in both the implementation and functioning of green energy systems.

Cities are not only made of buildings, people and infrastructure. Indeed, cities with the highest quality of life are well known for their open spaces. **Every city is an ecosystem, and maintaining its good status is crucial for the health and happiness of city residents.** This implies granting a good balance between green and built areas, sustaining biodiversity, restoring natural habitats, and providing ecological corridors for wild species.

The European Union has a Strategy on Green Infrastructure. This can be defined as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings [5]. Indeed, green areas are not only spaces for recreational activities; they also play a role in preserving natural environments, absorbing CO₂ emissions, improving air quality, and even preventing natural disasters, for example reducing rainfall runoff.

Moreover, green areas and infrastructure play a major role in contrasting urban heat islands, since they cool the air temperature, with positive effects on vulnerable people, particularly during heat waves. Furthermore, green areas represent assets that can contribute to other policy areas, creating jobs and opportunities for community development, for example.

Satellite imagery carries information to both design and manage green areas. It helps city planners to decide on where to place new parks, provides information on vegetation types and status, allows for the mapping and monitoring of habitats, and it supports policies aimed at reducing air temperature and pollution by restoring and protecting natural lands, ecological reserves, wetlands, and other green areas within and around cities.

Municipal waste accounts for only about 10% of the total waste generated in Europe. However, it has a very high political profile because of its complex character, due to its composition, its distribution among many sources of waste, and its link to consumption patterns. In 2015, in the EU-28 cities generated 477 kg of waste per capital, 44 kg less than in the year 2000 [6].

Cities (and local authorities) are generally responsible for collecting the household part of municipal solid waste. Satellites can help city managers in their efforts to reduce the impact of human consumption on the environment, people's health, and the city's ecosystem.

Satellite imagery helps spotting illegal dump sites within and around cities, which could harm soils, water, and eventually the food we consume. Satellite navigation is instead already used to optimise bin collection services, track hazardous waste, and build connected bins.

As the initiatives to better manage waste are flourishing among European cities, we expect in the next years the creation and further development of new and existing services relying on satellite data

Satellite Applications for Efficient Cities



Fig. 5 List of satellite applications for efficient cities. © Eurisy

Sustainable cities include social, economic and environmental considerations in designing and managing the urban infrastructure, its roads and transport networks, buildings, green areas, and public services. Integrated development strategies take into account diverse territorial needs within and outside the city, including its peripheral areas and surroundings. Satellites can support city administrations to better manage urban assets and services, and also to better understand the interconnections among the different assets and services of the city and between the city and its hinterland.

Growing urbanisation makes it necessary for city managers to have a precise overview of soil status and of land uses. A smart sustainable city is indeed one in which residential areas, green spaces and services are equally distributed, and a good proportion exists between the green volume and the built “grey” volume, which is a necessary condition not only to protect cities’ ecosystems and biodiversity, but also to grant a healthy life to their inhabitants.

As compared to other surveying techniques, satellite imagery offers a unique overview of land uses which is objective and comparable over time: satellite-based maps are already used in several cities worldwide to map land features and uses, create and update **cadastral** maps, plan and monitor the **access to services** and green areas and **soil status and subsidence**, and even to evaluate property taxes, among many other uses. Satellite imagery and navigation are used to create urban **3D maps**, allowing public managers to visualise and virtually test different scenarios for the future development of the city.

Satellite imagery is, or it will be, an integral part of cities’ **Geographical Information Systems (GIS)**. Where different GIS exist for different uses, they can potentially be combined by integrating layers of satellite imagery for the use of different municipal services.

Efficient and reliable transport systems are of paramount importance for cities. They are fundamental for cities’ liveability and also for their economic competitiveness, fostering both business and tourism. The sector includes both private and public forms of transport (including trains, buses, trams, ferries, tube lines, cars, cycling and walking) and the possibility to shift among them. Indeed, being able to move around easily and having access to reliable information on itineraries, timings and traffic status facilitate the everyday life of cities’ inhabitants. Optimising transport and mobility while encouraging “ecofriendly” ways of transport also helps decrease pollution rates, with positive effects on residents’ physical and mental health. Indeed, **urban mobility accounts for 40% of all CO2 emissions of road transport and up to 70% of other pollutants from transport [7].**

Satellites can facilitate transport in cities in several ways and many of their applications, notably those based on satellite navigation, have already proven their efficacy. Indeed, satellite navigation is used to **monitor** the position of **public buses, trams and shared car and bike systems** in many European cities, providing **information on timings and itineraries** in real time. Satnav is also used to **optimise traffic lights** and to **monitor traffic fluxes**, collecting data that traffic managers will use to improve and regulate the circulation. It is also employed to monitor the **transport of dangerous goods**, minimising the risks of their transit within cities.

Satellite navigation, in combination with Earth observation, is used to monitor the effects of traffic on the street pavement. In the near future, Satnav will be an essential component of **unmanned vehicles**, as it is already the case in some pioneering cities. The versatility and wide availability of satellite navigation signals offer concrete opportunities to support urban transport and more innovative solutions are expected to emerge in the coming years.

The first concern of city administrations when dealing with built areas is the quality of the soil. To make sure that new and existing buildings and infrastructure are safe and sustainable, it is necessary to have a precise understanding of the hydrogeological features of the land and its changes. As an example, in cities built on soft soil (with a high concentration of water), soil subsidence could cause serious damages to people, street pavements and buildings. It is hence necessary to monitor soil status and movements and to be able to foresee them to intervene before the damage happens.

City administrators also need to have a constant and complete **overview of the transport, energy and water networks**, to make sure that they function, that all residents have access to them, and that new developments are based on a holistic approach.

Satellites can help city managers making urban infrastructure and buildings more sustainable: satellite imagery allows for the precise mapping of buildings and infrastructure. It is also widely used to monitor **soil subsidence** and the risk of slopes with great accuracy, allowing city administrators to implement works where it is most urgent, with no need for costly field surveys.

Furthermore, satellite images, combined with ground sensors, allow for the identification and monitoring of **urban heat islands**, and for the identification of correlations between soil sealing, building materials and temperature. City planners can hence recommend construction materials according to the specific needs of the areas in which new buildings are created. Satellite imagery can be used to test different **traffic and construction scenarios**, and their impact on air quality, and to design new urban infrastructure accordingly. Satellite navigation is also useful in mapping buildings and infrastructure, and it is already employed to verify the accuracy of **new buried optic fibre**, gas and electric lines.

CONCLUSIONS

To address the challenges of urbanisation, it is today necessary to develop new integral approaches to city management, leading to sustainable urbanisation. A city is sustainable when decisions are taken by considering their effects with a holistic approach, taking into account different areas, such as transport, health, environment, infrastructure and education, and their correlations.

Satellites alone cannot fight global warming or inequalities, but they offer data and signals that can be used to improve the life of those inhabiting urban areas.

Satellite imagery allows for an integrated view of land uses and infrastructures and it is already employed by city managers, for example to target soil and infrastructure maintenance works where they are most needed.

Satellite navigation is a precious tool to improve city management, in particular to monitor and optimise public and private transport. Indeed, satellite navigation has today a crucial role in providing real-time information on public transport and in the implementation of intermodal transport systems in cities and their hinterlands. Numerous apps use satellite navigation signals, e.g. to help persons with disabilities in their daily movements or to enable residents to access information about public services and provide feedback to their local authorities.

Satellite communication is also used in cities, to connect rescue teams when other connections are down, or to perform health checks in public spaces, among others.

These are just a few of the many existing applications [8] of satellite data and signals which can help building safe, inclusive and resilient cities, as envisaged by the United Nations Sustainable Development Goal 11 [9]. Seizing the impacts of satellite applications on urban areas is just a first step to envisage the full exploitation of these tools to build sustainable cities.

The new constellations of satellites and services deployed by single governments and by the European Union (Galileo, Copernicus and EGNOS) will provide us with additional tools to enhance economic, social and environmental well-being in cities. It is hence fundamental that cities are prepared to profit from these resources and that their needs are carefully assessed and considered when developing new products and services based on satellite applications.

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EXPLORING CO-BENEFITS OF ACTIVE TRANSPORTATION IN A LOW-CARBON FUTURE: A CASE OF TWO INDIAN CITIES

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ABSTRACT

Over recent years, cities in the Global South have shown a shift from public to private modes of transport, along with longer trip lengths, contributing to high GHG emissions. Many rapidly motorizing countries are experiencing a steep decline in physical activity, contributing to 5.3 million deaths annually. Even with inadequate infrastructure and a poor level of service, Indian cities continue with high modal shares of low-carbon transport modes like non-motorized transport (NMT) (walking and cycling) and public transport (PT), pre and post the COVID-19 pandemic. With increase in use of these active transport modes, CO₂ emissions and inactivity can be substantially reduced.

Literature suggests that high dependence on personal mobility overlooks the needs of those having a restriction on personal vehicle use (like urban poor or women), causing inaccessibility. These are mainly ‘no choice’ walkers and cyclists, who need a safe, segregated, and unobstructed space to walk or cycle, away from the mixed traffic and encroachment. Additionally, children, elderly and differently-abled have special infrastructure design needs for accessibility. For longer distances, reliable mass-transit systems like the bus, metro-rail or the paratransit, integrated with the non-motorized transport are essential to promote healthy lifestyles by reducing personal motorized vehicle use, increasing physical activity and improving air quality.

This paper discusses the current state of active transportation modes and their co-benefits in two Indian cities of contrasting nature; Surat, a metropolitan industrial city with 5.9 million population and Udaipur, a tourist city with 0.5 million population and a frequent international footfall. The analysis presented is informed by online consultations and in-person field surveys disaggregated by various modes, income groups, gender, and special needs undertaken during the COVID-19 pandemic. It lays out recommendations to improve active transportation and co-benefiting health, sustainability, and climate action.

KEYWORDS

Active transportation; Non-motorized transport; Low-carbon transport; Health; Sustainable cities

INTRODUCTION

Active transportation consists of transport modes that do not operate on a motor engine. Globally, walking and cycling (collectively also known as non-motorized transport), are termed as active transport modes as they are healthier in comparison to motorized modes (WRI, 2021). Many rapidly motorizing countries are experiencing a steep decline in physical activity, contributing to 5.3 million deaths annually (Welle et al., 2018). Research suggests that with the increasing urbanization, about 80% of youths worldwide have insufficient levels of physical activity, increasing their exposure to non-communicable diseases (Oyeyemi & Larouche, 2018). This gave rise to the Active Transport movement in the Global North, where planners and policy makers pushed for prioritization of non-motorized infrastructure and awareness campaigns to build a walking & biking culture (UNCRD, 2018). Since then, active transport is believed to play a unique role to supplement an efficient and equitable transportation system by increasing access to other modes (WRI, 2021). It has various direct and indirect benefits like increased user convenience and security, reduced congestion, lower travel costs and increased level of physical activity. In country such as India, it also is the ‘no cost’ or cheapest mode of mobility particularly for the low-income populations and women among them whose control over their incomes is often limited (Mahadevia, Gender Sensitive Transport Planning for Cities in India, 2015). Active transport supports liveable communities and enhances public realm, while maintaining a neutral carbon footprint (Litman, 2021). Active transport regained popularity during the recent outbreak of COVID-19 pandemic, as it was the only safe and reliable mode of transport amidst lockdowns (Zafri, Khan, Jamal, & Alam, 2021).

In the Global North, active transport is often perceived as a favourable first- & last-mile option, or a preferable transport choice for shorter trips. Hence, literature from these regions suggests a high synergy with sustainable mobility. While in the Global South, active transport users are often captive users who solely rely on non-motorized transport for their work/ primary trips and walk or cycle much longer distances than their Global North counterparts. They are termed captive users as they walk or cycle due to low incomes not affording them any other mobility choices and are term ‘no choice’ walkers or cyclists (Jain & Tiwari, 2013). As this study is grounded in an Indian context, it focuses on active transport as a primary mode choice for all purpose trips as well as a first- & last-mile option for sustainable motorized modes like public transit and intermediate public transport.

Even with inadequate infrastructure and a poor level of service, Indian cities continue with high modal shares of low-carbon transport modes like non-motorized transport and public transport (Pai, 2014). The mobility patterns discerned from the Census of India data and the growing literature on active transport in Indian cities show prevalence of non-motorized transport in urban India since the late 1960s. non-motorized transport, especially walking, continued to contribute to around half of a city’s mode share across the nation (Table I). However, urban local bodies fail to invest in upgradation of pedestrian and bicycling infrastructure, resulting in a degraded quality of service that causes road safety and accessibility challenges, in turn reducing mode preference for non-motorized trips. It also leads to shift to motorized transport modes with improvement in incomes. The low-prioritization of non-motorized transport in cities, coupled with rising income levels, lead to a steep increase in vehicle ownership, and in turn, a high rate of motorization and cause local sustainability issues (Jain & Tiwari, 2013). With the rising debates around the future of mobility in Indian cities, the study aims to investigate the needs of active transport users and propose a strategy that maximizes the co-benefits of active transport, in a low-carbon mobility scenario.

Table I: Share of trips on foot and cycle in 10 Indian cities

| | Chennai | Delhi | Mumbai | Ahmedabad | Bangalore | Pune | Bhopal | Indore | Jaipur | Mysore |
|-------|---------|-------|--------|-----------|-----------|------|--------|--------|--------|--------|
| Walk | 22% | 21% | 27% | 13% | 19% | 22% | 49% | 27% | 37% | 34% |
| Cycle | 9% | 12% | 6% | 19% | 6% | 11% | 4% | 20% | 7% | 17% |

From Transport in Cities – India Indicators, (Embarq, 2009)

The paper reviews the need and importance of active transportation in the global and Indian context. It explores the relationship of non-motorized transport with low carbon mobility and selected sustainable development goals across the aspects of access, safety and health. In the next section, the methodology of the study is conversed at length discussing the literature review, existing situation analysis, data collection and assessment of interactions with SDGs. Further, the paper highlights these interactions assessed through desktop assessment, in-person surveys as well as interviews and discussions with the city level stakeholders, with respect to three scenarios- the existing situation (2016), low carbon proposals (2030) and SDG-enabled scenario (2030). The last section identifies challenges and gaps in the low carbon mobility plans and lays out recommendations under the SDG-enabled scenario for improved and inclusive active transportation in the two cities.

RELATIONSHIP OF ACTIVE TRANSPORT WITH LOW CARBON MOBILITY & SUSTAINABLE DEVELOPMENT

The Sustainable Development Goal framework discusses the interactions between human development and the environment due to rapid and extensive climate change mitigation. It suggests that policy interventions informed by a better understanding of synergies and trade-offs can come together to create transformational change. IPCC's 1.5°C Report (Sims R., et al., 2014) highlights the transport sector's relationship with various Sustainable Development Goals (SDGs). After a thorough literature review of urban transport and SDG interactions for all seventeen SDGs, six relevant SDGs, SDG 1- End Poverty, SDG 3- Health & Well-being, SDG 5- Gender Equality, SDG 8- Decent Work & Employment, SDG 11- Sustainable Urbanization and SDG 13- Climate Action, were selected for our study and their relationship with Active Transport have been discussed in this paper.

Economic growth and higher purchasing power increase travel demand, especially motorized travel demand, leading to more frequent and denser traffic congestion and environmental impacts (Bull, 2003). These impacts include high energy consumption, air pollution and noise pollution, resulting in unhealthy urban ecosystems and communities (Sims R., et al., 2014). Realising this, numerous countries have stepped up to create plans for sustainable transport, as evidenced in the 'Handbook on Nationally Appropriate Mitigation Actions (NAMAs)' (Eckermann, et al., 2015). In India, National Transport Action Plans and various city level Low-Carbon Mobility Plans (LCMPs) or Comprehensive Mobility Plans (CMPs) have been prepared to reduce GHG emissions from urban transport without compromising on mobility. Evidence from all LCMPs/ CMPs in India shows that low-carbon mobility generates plenty of co-benefits with sustainable development (that prioritizes safe, affordable, accessible and inclusive transport for all) (SLOCAT, 2021); (United Nations, 2015). Co-benefits include (i) improved quality of life with better road safety (SDG 3 and 11), lower health risks and increase in time savings (SDG 3 and 5); (ii) decreased damage to local environment by better air quality, less soil degradation and less noise (SDG 11 and 13); (iii) better energy security with lower energy costs, less imported fuel and diverse energy supply portfolio (SDG 11 and 13); and (iv) stronger economic development with better income opportunities, local job value creation and increased private investments (SDG 1 and 8) (Eckermann, et al., 2015); (Thilakshan & Bandara, 2019); (Lah, 2015). For the purpose of the paper, the above stated dimensions of sustainable mobility are combined to form three themes- accessibility and affordability as "Access for All", safety and security as "Safety while using non-motorized transport" and environmental impact as "Health Outcomes of non-motorized transport".

Access For All

Accessible transport systems enable an individual to reach social, educational and employment opportunities as well as other services such as healthcare. Inefficient systems that fail to follow universal design guidelines are not inclusive to all (especially vulnerable groups) (International Transport Forum, 2017). Availability of diverse transport modes, quality of service of transport systems, inter-connectivity of various transport systems elements and transportation affordability govern transport access. Transport systems are affordable when individuals have the financial ability to use modes without compromising purchase of other basic necessities like housing, food, health and education (United Nations, 2015). Owing to unreliable public transport in most cities of the Global South, and high costs associated with personal transport, urban poor and other marginalized groups are likely to spend a high share of their household income on transport, (United Nations, 2015) (Starkey & Hine, 2014), forcing them to walk and cycle to work (SDG target 1.4 and 8.3). Large proportions of non-motorized transport users in the Global South are captive users having restricted access to other transport modes (Mahadevia & Advani, 2016); (Mahadevia, Gender Sensitive Transport Planning for Cities in India, 2015). This curbs their sphere of economic opportunities, exacerbating their poverty (Baker, Basu, Cropper, Lall, & Takeuchi, 2005), especially for women. Women tend to chain their trips with activities like picking up children from school, purchasing household food items, and other tasks related to the care economy (Bhatt, Menon, & Khan, 2015) and experience a greater time-poverty. As a result, they are known to forgo an opportunity to work or socialize outside their neighbourhoods if they perceive transport fares and services to be expensive and unreliable (Allen, 2018). (SDG target 5.4)

Insufficient access to public transportation demands a re-design of existing mobility environments, emphasizing on implementation of environmentally conscious infrastructure for walking and cycling, for all (including children, women, elderly and differently abled) (SDG target 11.2 and 11.7) (United Nations, 2015). Additionally for a longer trip on sustainable modes like the mass transit, the different components that comprise the access leg or the "first mile", the public transport/ paratransit mode or the "trunk mode", followed by the egress leg also known as the "last mile". The first and last mile modes in many cases are walking and cycling. Literature suggests that these modes may be inflexible and slow, bringing disutility for users (Scheltesa & Correia, 2017). Hence, these modes are the most important part of their trip as they enhance ridership on the public transit.

Safety while using Non-motorized Transport

Non-motorized transport users need a safe, segregated and unobstructed space to walk or cycle, away from the mixed traffic (MoUD, 2014). The design of streets gives visual and physical clues to the users (where to walk, how fast to drive, where to ride, etc.), critical for resource constrained regions like India where enforcement is typically lax (Bhatt, Menon, & Khan, 2015). In the case of cities with a rich natural and cultural/ built heritage, implementing pedestrianization/ slow streets across mixed land-uses strengthens heritage preservation and tourism/ recreation oriented revenues (SDG target 11.4).

Limited or absence of essential elements like pedestrian crossings, traffic signals and lights, raised medians, road signages lead to chaotic traffic conditions (for all users) and contribute to unsafe street environments (Arora & Tiwari, 2006). These factors create an inconvenient and inaccessible road space for all (SDG target 3.6). Road crash fatalities and associated serious injuries are an economic and social development issue that disproportionately affects the low and middle-income groups in developing countries. Often, lopsided share of funds facilitates the use of private vehicles, while the needs of low-income NMT users are ignored (Pucher, Korattyswaropam, Mittal, & Ittyerah, 2005) (SDG target 1.5). Globally, over one million people are victims of road fatalities every year (WHO, 2021). Associated costs of suffering caused by human loss amounts to 1-3 percent of their GDP in many countries (SDG target 8.8). Standards on road infrastructure, traffic rules, awareness programs need to be implemented with a focus on vulnerable road users i.e., pedestrians, cyclists, women, children, elderly and differently abled (United Nations, 2015). As per SDG target 5.2, along with road safety and comfort, safety from sexual harassment is vital for women's mobility. Women are at higher risk of being victims of crime and violence, and tend to experience curbed access to economic and civic opportunities, making safe streets fundamental for women's empowerment (Allen, 2018).

Health Outcomes of Non-motorized Transport

India's National Action Plan on Climate Change (NAPCC) recognises the role of NMT to reduce GHG emissions (MoUD, 2014). Studies show that unless active transport modes (pedestrians and bicycles) increase, CO₂ emissions cannot be substantially reduced (Woodcock, Banister, Edwards, Prentice, & Roberts, 2007). And enhancing pedestrian facilities is associated with decreasing preference for motorized modes and hence lesser CO₂ emissions. (SDG target 3.9, 11.6 and 13.2)

Active transport like walking and cycling promotes healthy lifestyles by increasing physical activity and improving air quality (MoUD, 2014). Exposure to vehicle exhaust emissions can cause cardiovascular, pulmonary, & respiratory diseases and other negative health impacts, severely affecting life expectancy (Lee & Greenstone, 2021) (SDG target 3.3 and 3.9). Transport-related human inactivity has also been linked to several chronic diseases, like risks of diabetes, cardiovascular diseases, obesity and high blood pressure, anxiety and depression (WHO, 2005). An increase in walking and cycling activities could therefore lead to various health benefits including reduced stress and anxiety. As per the finding of a study in London, walking or cycling for an average of 20 minutes a day could reduce various ailments like type 2 diabetes cases by 35-50%, colon cancer cases by 30-50%, depression cases by 20-30%, heart diseases and Alzheimer's by 20-35%, etc. (Transport for London, 2017) (SDG target 3.3 and 3.9). Also, non-motorized transport can lead to lower expenditures incurred towards transport and hence the savings can be used for other purposes including for health care, nutritious food and education, giving rise to economic independence (UNCRD, 2018) (SDG target 3.4).

Additionally, walking and cycling improve the social life and build the sense of community, improving well-being and civic engagement (Biggar, 2020). A study in the city of Preveza revealed that an increased number of residents positively affected their own decision to use bicycles (Karanikola, Panagopoulos, Tampakis, & Tsantopoulos, 2018) (SDG target 3.4). Hence, positive behavioural change can be achieved with a transformation in urban forms and ecosystems.

RESEARCH QUESTIONS AND METHODOLOGY

Studies on transport-SDG interactions often have a broader unit of analysis (i.e., a geo-political region like the European Union, or countries), failing to present evidence at a local level such as that of a city or an urban agglomeration. Hence, the study aims to fill the gap by being grounded in two Indian cities Surat and Udaipur. Surat Urban Development Area (SUDA) and Udaipur Urban Control Area (UUCA) (Figures 1 and 2) are selected due to their well-developed low-carbon mobility plans, contrasting socio-economic profiles and feasibility of fieldwork. Research questions of the study are- (i) What are the travel characteristics and needs of non-motorized transport users in Surat & Udaipur? and (ii) What needs of the non-motorized transport users could leverage the co-benefits of SDGs and low-carbon mobility? The methodology consists of following steps as below:

- 1. Desktop Assessment of Existing NMT Infrastructure & SDGs:** A critical assessment of the cities' non-motorized transport infrastructure was conducted viz-a-viz six relevant SDGs. Each interaction between non-motorized infrastructure and SDGs was tabulated in terms of synergy, trade-off, mixed impact or neutral for the both case-study cities. To triangulate the findings from the desktop assessment, probing areas were identified and pursued in fieldwork.
- 2. Primary Data Collection:** Travel patterns and mobility challenges were captured through on ground data like user surveys by mode, household surveys, tourist surveys and local shop owners'/ vendors' surveys, between October and December 2020. Approximately 0.05% of the total population was considered as the sample size for Surat (5.9 million population) and 0.1% for Udaipur (0.7 million population). To aid this, three online focus group discussions were conducted (due to COVID-19 pandemic), with five to six participants each, consisting of experts, civil society workers as proxies of vulnerable groups, and professionals working on related projects.
- 3. Assigning Assessment Score:** A review of the current dataset from the mobility plans and fieldwork was conducted against various performance standards and Service Level Benchmarks, published by the Ministry of Urban Development (MoUD). The authors assign the assessment scores to each non-motorized transport-SDG interaction at the target level. Each interaction is assessed into synergy (+1), trade-off (-1) or mixed impacts (+1) (discussed in Table V). If both above stage indicate a clear synergy or trade-off, then respective scores (+1/-1) are assigned, but if either stage indicates the opposite impact, a mixed score is assigned (± 1). The value 0 indicates absence of impact. Based on this, recommendations were formed to maximize the co-benefits of non-motorized transport under the three identified themes- Access, Safety and Health (as explained in the next section).

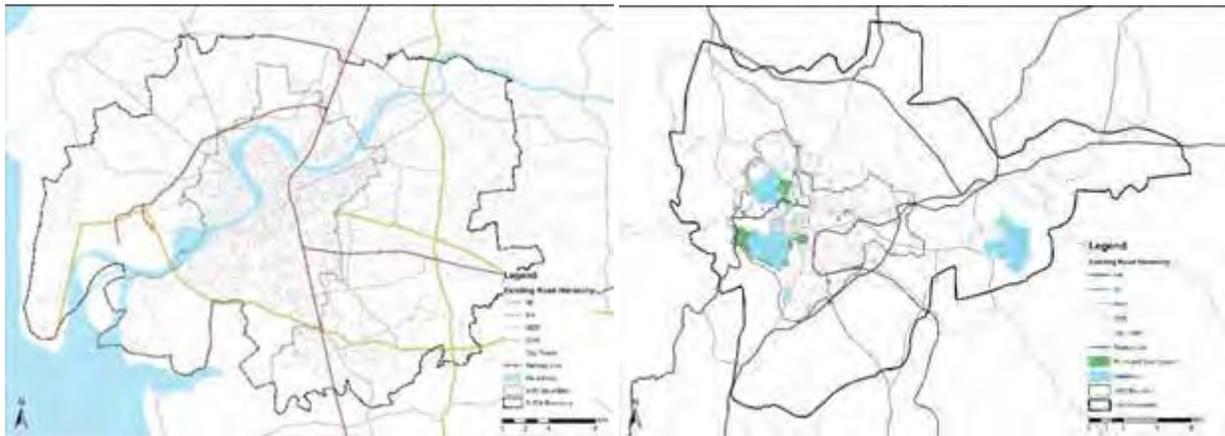


Fig. 1 and 2: Surat Urban Development Area (SUDA) and Udaipur Urban Control Area (UUCA)

NMT Users Travel Experiences in Surat and Udaipur

Surat is a metropolitan city with an urban agglomeration area of about 1351 sq. km and a population of 5.9 million (2016 population). It is a polycentric city with an incomplete ring-radial road network, and a gross population density of 6,190 persons per sq. km. Textile and diamond industries form the economic base of the city. Udaipur has a population of 0.8 million (2016 population) and an urban agglomeration area of 348 sq. km. It is a small city with a preserved cultural heritage, making tourism its main industry. Udaipur traditionally a compact city with a dense, ring-radial road network, is now rapidly expanding along two highways, creating high travel demand. Both the cities serve a large floating population.

50% of trips in Udaipur and 42.3% trips in Surat are by non-motorized transport (Surat CMP, 2016; Udaipur LCMP, 2013). Like other cities in India, trip choices in are gradually shifting from non-motorized modes to personal motorized modes like two-wheelers and cars, causing an inequitable distribution of road space. Since 1988, the share of NMT users in Surat decreased from 65% to 43% in 2016, out of which the share for cycling dropped by 17% (Surat CMP, 2016) (Fig. 3). Increased urbanization in both cities accompanied with higher household incomes, has led to a steep increase in motorization and 2.5 times increase in traffic levels.

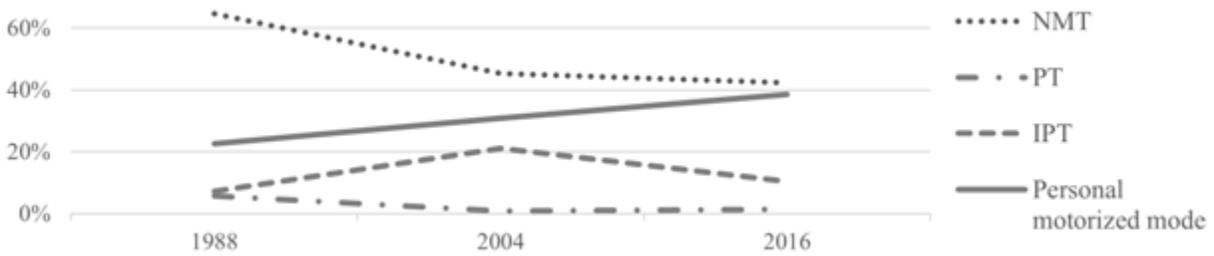


Fig. 3: Mode share in Surat over three decades (Source: Surat CMP, 2016)

Profiling Non-motorized Transport Users in Surat and Udaipur

Non-motorized transport users in both cities travel unusually long distances, often similar to that of motorized transport users. The average trip length for walking trips is 2.9 km in Udaipur and 2.5 km in Surat, while for cycling it is 5 km in Udaipur and 4 km in Surat. The travel time for walking in both cities is close to 28 minutes (Surat CMP, 2016; Udaipur LCMP, 2013), almost 2.5 times the city and national averages, indicating non-motorized transport users experience longer travel times, subjecting them to time poverty and related health issues. Plotting NMT users by income groups highlights that urban poor have the highest dependence on non-motorized modes for work trips. Out of the total pedestrians and cyclists, 50% in Surat and 54% in Udaipur (Fig. 4) belong to low-income groups (household income of \$350/month) (Surat CMP, 2016; Udaipur LCMP, 2013). Users' mode preference showcases the captive nature of non-motorized transport users; 42% users in Surat and 32% in Udaipur report unavailability of personal vehicles as the leading reason for choosing non-motorized transport, followed by affordability of walk or cycle trips. Furthermore, lack of a robust and affordable public transport network results in low bus ridership, leading to reliance on non-motorized transport, especially for vulnerable groups (Primary survey, 2020). Disaggregated data on gender and income in the city documents highlight poor women have the highest dependence on walking in both cities.

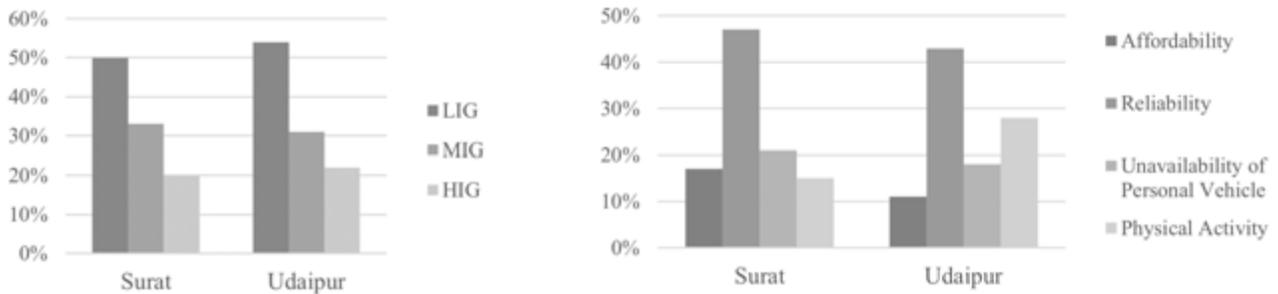


Fig. 4 and 5: Proposed Footpath and Cycle Network in Surat and Udaipur (Source: Primary Survey, October-December 2020)

NON-MOTORIZED TRANSPORT INFRASTRUCTURE ASSESSMENT

Like many Indian cities, Surat and Udaipur have poorly developed and maintained non-motorized transport infrastructure. Only 20% of Surat's roads have footpaths, and only 7.6% have cycle tracks. Out of the total 115 major junctions in Surat, only 38% have been signalised. 25% of cycle tracks are encroached by parking and only 33% of interchanges have dedicated cycle parking facilities. About 20% of the roads have no tree cover along the network. As per Ministry of Urban Development's (MoUD) Service Level Benchmarking (SLB) handbook, the overall Level of Service (LOS) for pedestrian infrastructure in Surat is 3, and for cycling infrastructure is 4 (Surat CMP, 2016). Despite pedestrian footfall in Udaipur (as high as 53,338 pedestrians/ day), non-motorized transport infrastructure including footpaths, cycle lanes/ tracks, pedestrian/ cycle crossings, street lighting is poorly designed and inadequate. Less than 1% of the roads have cycling and footpath infrastructure in the city. The LOS for non-motorized transport infrastructure in Udaipur is rated as 4.0 (Udaipur LCMP, 2013).

User Perception of NMT Infrastructure in Surat and Udaipur

This insufficient and ill-maintained infrastructure along with high conflict between motorized vehicles and NMT users leads to unsafe street environments (Jennings, 2016). Non-motorized transport users are often forced to walk or cycle on the carriageway sharing it with passenger and freight traffic, leading to an increased risk of fatalities and serious injuries due to road crashes. 50% of all fatalities in the city include pedestrians and cyclists (Surat CMP, 2016; Udaipur LCMP, 2013). This poorly-maintained and absent non-motorized transport infrastructure also increases women's fear of violence and curbs their mobility (Mahadevia; Lathia, 2016). Only 7.5% pedestrians and 7% cyclists in Udaipur in our survey ranked the streets as safe (Udaipur LCMP, 2013). As per the household surveys, 20% households located in 1 km of an arterial street/ highway/ freeway reported increased encountered road accidents. Further inquiry in Surat revealed that about 42% of users had been hit by a car or two-wheeler within the past three years, either on the vehicular side of the road or the footpath/ cycle lane (Primary survey, 2020).

Majority of pedestrians and cyclists in both cities rated the NMT infrastructure as unsatisfactory. 74% of the non-motorized transport users in Surat and 66% in Udaipur find the infrastructure discontinuous & disruptive, out of which more than 30% reported frequently broken infrastructure. Moreover, 56% users in Surat and 43% in Udaipur find footpath/ cycle track widths are insufficient and uncomfortable, needing drastic improvements. Additionally, in Udaipur 98% users mentioned that they cycle on the carriageway. 55% of the non-motorized transport users in Surat and 44% in Udaipur reported that the footpath/ cycle lanes are difficult to use during heavy monsoons and hot summer days; 41% non-motorized transport users in Surat reported heavy water logging in their areas, 18% reported compromised visibility during monsoon and 52% reported lack of shade from trees or built environments causes added discomfort during summers (Primary survey, 2020).

Assessing Co-benefits and Externalities of Non-Motorized Transport

The existing situation poses negligible co-benefits, like higher levels of physical activity among non-motorized transport users. But studies in the Global South context show how long distances on foot and cycle, often take a toll on the non-motorized transport users health (Interface for Cycling Expertise, 2000). Increasing motorization and construction of flyovers, exposes non-motorized transport users to a disproportionate amount of negative externalities, like increased GHG emissions, air pollution, road accidents, longer travel time and other health issues.

As discussed in the mobility plans for both cities, dependency of private vehicles and reliance on fossil fuels contribute to an increase in the greenhouse gases CO₂, CH₄, N₂O and ozone precursor gases like CO, NO_x and NMVOC (UNEP, 2019). The per capita per year GHG emissions in Surat and Udaipur is 0.22 and 0.11 tonnes CO₂ respectively. Around 80% of the total GHG emissions in Surat and Udaipur are attributed to personal motorized vehicles (2- & 4-wheelers). The urban passenger transport sector emits a total of 1.4 tonnes and 0.18 tonnes of PM_{2.5} in Surat and Udaipur respectively. Out of this, over 75% is caused by personal motorized vehicles (Surat CMP, 2016; Udaipur LCMP, 2013). Non-motorized transport users are usually the most susceptible to GHG emissions and related health concerns, causing health equity challenges in both cities. In Surat, 32% households reported increased exposure to air pollution and related health concerns, followed by noise pollution & longer travel times (16% households each) and higher levels of stress and anxiety (12%) (Primary survey, 2020). Indirect impacts of poor non-motorized transport manifest various economic challenges. Broken or discontinuous footpaths lead to curbed access for the poor, especially street vendors, who face difficulties reaching their place of work (ITDP, EPC, & GICEA, 2011). Also, lack of vending spaces or an indecent work environment has a negative impact on their revenues largely affecting tourism, loss of productivity and high opportunity costs.

NON-MOTORIZED TRANSPORT PROPOSALS & RELATIONS WITH SDGs

The Comprehensive Mobility Plan-2046 for Surat and the Low-carbon Comprehensive Mobility Plan-2041 for Udaipur propose sustainable low-carbon solutions to improve active transport and produce co-benefits with access to opportunities, safety and health in both cities. In this section these transport interventions' synergies and trade-offs with the SDGs are discussed.

LCMP Proposals (2030)

In both cities, the mobility plans provide for an improved access to public transport and intermediate public transport through proposing an improved quality and coverage of non-motorized modes between high density land uses and city bus services. Along with walking and cycling being an important last mile option for long-distance trips, it aims to promote these active transport modes

for shorter trips to reduce the dependence on personal motorized modes and the total vehicle kilometres travelled. Majority of the pedestrian and cycling network is planned along the transit corridors covering residential areas designed as “Complete Streets” that follow the Universal Street Design guidelines ensuring an easy, safe and inclusive access to public transit and surrounding mixed-use establishments. This safe, inclusive, and accessible infrastructure is essential along with favourable land-uses for a successful walking and cycling culture in the migrant city of Surat and the tourist city of Udaipur.

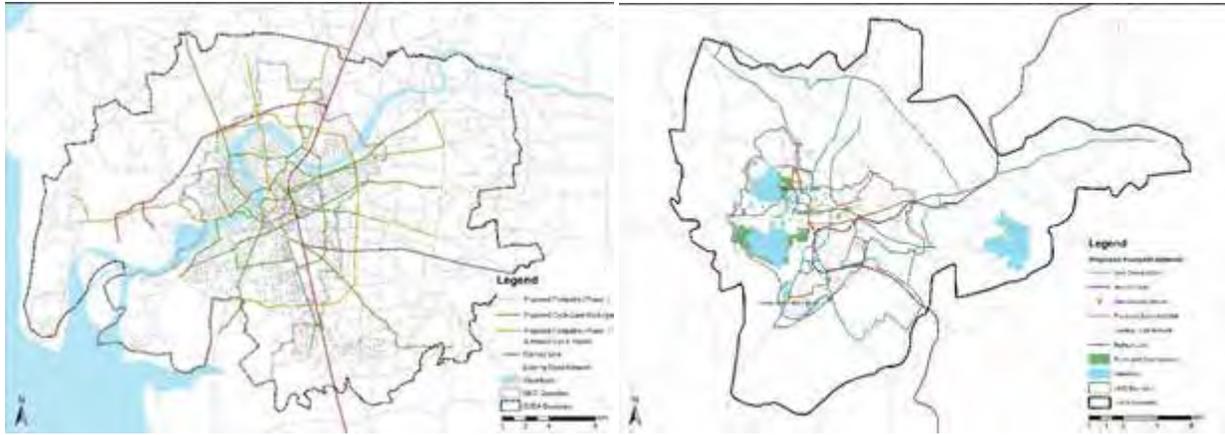


Fig. 6 and 7: Proposed Footpath and Cycle Network in Surat and Udaipur

In Surat, street infrastructure like street lights, zebra crossings, signalized junctions, and identification of mid-blocks (to reduce trip distance) will ensure safety of pedestrians and cyclists, especially through identifying safe movement routes that connect residential areas to work areas, schools, colleges, and transit stations. The existing footpath network is proposed to be upgraded to a uniform width of 1.8 m. An additional 418 km of new footpaths of widths more than 1.8 m will be added, out of these 130 km of footpath is along collector and distributor roads falling within the accident-prone areas. Similarly for bicycle infrastructure, 288 km of new bike lanes will be added (Fig. 6). The proposal aims to popularize bike-sharing schemes and includes several bike-sharing interventions with over 16,000 cycles and intelligent transport systems and additional docking points around major attractions and public transport and paratransit stands. To improve road safety and foster safe, accessible and inclusive access, especially for the transit-oriented development area, the mobility plan discusses formulation of an Accident Management Plan, Signalization Plan and establishing an Accident Monitoring Cell. The proposal also talks about integration of public transport modes with non-motorized transport modes with a 240 km long multimodal transit network with 37 planned interchange stations. Along with this, transit ready streets would have pedestrian infrastructure along bus priority lanes. This would enhance first and last mile connectivity (Surat CMP, 2016).

In Udaipur, 133 km of “obstruction-free” footpath network with a desirable width of 2m or above is proposed, along with upgrading around 10 km of existing footpaths with a minimum width of 1.5m (Fig. 7). Provision of signals for pedestrian crossings is proposed at 19 intersections to decrease crossing time and increase safety and night-time semi-mast lights installation at all junctions is proposed to improve safety. Along with this, all signalized intersections will have pedestrian crossings and all busy intersections will have handrails to ensure pedestrians can safely cross at the Zebra crossing. To promote the use of bicycles in Udaipur’s slightly challenging terrain, the low-carbon mobility strategy proposes cycle tracks of around 40 km on a few major roads (Fig. 7). The proposal also aims to popularize bike-sharing schemes, especially among students and tourists by introducing bike-share docking points around major tourist attractions and other important areas. To further promote tourism through safe, accessible and inclusive non-motorized transport infrastructure, the low-carbon mobility plan proposes 3 vehicle-free heritage walk routes in and around the walled city (Udaipur LCMP, 2013).

Table II shows the comparison of existing and proposed infrastructure/ services in Surat and Udaipur. In Surat, it is observed that the NMT network coverage is improved, but not as per ideal requirements of more than 75%. The level of service is also enhanced, but not to the optimum level of 1.0. In Udaipur, both footpath and cycling infrastructure is still weak and absent at various major locations.

Table II: Existing and proposed non-motorized transport infrastructure in Surat and Udaipur

| | Surat | | Udaipur | |
|---|-------|-------|---------|-------|
| | 2016 | 2030 | 2016 | 2030 |
| Share of congested roads | 14% | 14% | ~26% | 5% |
| Number of signalised intersections | 44 | 178 | 7 | 26 |
| Footpath network coverage | 20% | 44.5% | 4% | 8.6% |
| Share of roads with street lights | 50% | n/a | 37% | 78.7% |
| Number of pedestrian crossings | 0 | n/a | 0 | 19 |
| Level of Service (LOS) of pedestrian infrastructure | 3.0 | 2.0 | 4.0 | 2.0 |
| Cycle network coverage | 7.6% | 25.8% | <1% | 2.4% |
| Number of public bicycle share stations | 0 | 64 | 0 | 4 |
| Level of Service (LOS) of cycling infrastructure | 3.0 | 2.0 | 4.0 | 2.0 |

From Surat CMP (2016) and Udaipur LCMP (2013)

Assessing LCMP Proposals and SDG Interactions (2030)

In both Surat and Udaipur, the proposal improves access to employment and civic opportunities for all (SDG 1, 5, 8 and 11), reduces emissions (SDG 11 and 13) and air/ noise pollution and related health hazards and increases physical activity, improving physical and mental well-being (SDG 3). Also, pedestrian and cycling infrastructure improvements particularly benefit the vulnerable groups, who are often captive users of non-motorized transport, by enabling them to safely reach other affordable, low-carbon modes like public transport (SDG 1, 5 and 11).

In Surat, comparing these non-motorized transport infrastructure improvements to a Business-as-Usual scenario, there is a 28% decrease in GHG emissions, a 37% reduction in road accidents and a 34% increase in the households that can access public transport (Surat CMP, 2016). Whereas in Udaipur, aiming to obtain more road length accessible by walking and cycling modes, the number of households residing within the 10 minutes' walk of the city bus system would increase from 16% in the Business-as-Usual scenario to 83% in the low-carbon mobility scenario. These strategies including improved lighting also propose to increase the perception of safety to use these active transport modes from 8 per cent in the Business-as-Usual scenario to 83 per cent in the low-carbon mobility scenario (Udaipur LCMP, 2013).

These proposals would improve mobility and access to opportunities for the otherwise “captive users”. However, in terms of the coverage and the quality of infrastructure, both mobility plans for non-motorized transport have further scope to improve. There is a need for increased coverage of pedestrian and cycling infrastructure than the proposed levels (especially in Udaipur) ensuring an ease of access and an integrated transport system for all. The quality of infrastructure (level of service) is proposed to be 2.0. This can be improved to 1.0 (the best), highlighting a wider reach.

MAXIMIZING CO-BENEFITS FOR AN SDG ENABLED FUTURE

The low-carbon mobility proposals manage to mitigate most trade-offs for both cities, as discussed in the above section. However, the fieldwork and the FGDs brought out many additional recommendations to amplify the synergies with SDG targets. 89% surveyed private vehicle users in Surat and 98% in Udaipur agreed to frequently use non-motorized transport modes if the quality of service improved (Primary survey, 2020). It is recommended that non-motorized transport infrastructure in both the cities should have a level of service of 1.0 (highest) with a network coverage of more than 75%.

Table III: Recommendations for improved safety by non-motorized transport users in Surat and Udaipur

| | Surat | Udaipur |
|--------------------------|-------|---------|
| Better speed regulations | 15% | 18% |
| Continuous footpath | 18% | 19% |
| Increased lighting | 15% | 10% |
| Pedestrian signals | 16% | 17% |
| Shaded footpath | 16% | 14% |
| Wider footpath | 20% | 20% |
| Total | 100% | 100% |

From primary survey (October-December 2020)

To improve access to opportunities- It is recommended that there must be strict implementation to ensure no obstruction (to be continuous in front of property gates, etc.) of footpaths and cycle tracks, paving the way for better access for all. All intersections should have pedestrian crossings with lane markings, zebra crossings, pedestrian signals and raised platforms to set apart users from motorized traffic. Another key intervention highlighted in the primary survey was pedestrianizing the walled city area. A majority of pedestrians, cyclists and tourists responded positively to pedestrianizing the walled city or implementing multiple one-way streets for reduced chaos on streets. Supporting this, a majority of local shop owners and vendors believe pedestrianization would improve their businesses and boost their revenues. Hence, the old city core in both cities should be pedestrianized in a way that they are disable-friendly and age-friendly, to allow access for all, operating within a specific time window- like 8 am to 10 pm. Needless to say, there is a need for a reliable bus or paratransit service and parking spaces available outside the walled city for the pedestrianization to work effectively.

Table IV: Local Shop Owners & Vendors in Favour of Pedestrianization in Surat and Udaipur

| | | Surat | Udaipur |
|---|---------------------------------------|-------|---------|
| Pedestrianization | Local shop owners & vendors in favour | 86% | 100% |
| Other recommendations for increased revenue | Parking provision and management | 55% | 10% |
| | Improved network coverage for PT/ IPT | 28% | 5% |
| | Improved NMT infrastructure | 10% | 65% |
| | Traffic management & others | 7% | 20% |
| | Total | 100% | 100% |

From primary survey (October-December 2020)

To improve safety on streets- The street design could be supplemented with tactical urbanism measures trying redesigning high-conflict intersections with refuge islands, smoother/ flattened turning curves and reduced carriageway widths, cycling lanes within mixed traffic and pedestrian and cyclist signals. This would also enable economic activities (like vending zones) along the streets improving livelihood. Adding to this, it is assessed that the proposed footpath width of 2m is insufficient for places with heavy foot traffic like tourist and commercial areas. Hence, the footpath width should be increased to 4m around commercial fronts, dense public places and tourist spots, like lake-fronts. Considering the safety aspect in both cities (especially Surat, since it has a mix of industrial and residential land use in its core city), implementing strict speed limits would reduce fatalities and other serious injuries of pedestrians and cyclists due to road crashes with private vehicles and freight movement. Raised pedestrian and cycle crossings at intersections are proposed, however the share and intensity is unclear. Hence, all intersections including motorized traffic are recommended to have a raised crossing for non-motorized transport users.

To increase health benefits- Both cities also have a potential for developing a cycle culture (considering the migrants in Surat and tourists in Udaipur), especially around E-bikes and bike-sharing infrastructure. In Udaipur, the plan fails to create a cycling network across the city. Hence, priority cycle lanes are recommended with the concept of “slow streets”. It is also suggested that the government organizes awareness drives like “Cycle 4 Change”, to improve accessibility of the vulnerable, specially the disabled, older adults, women and children. To reduce the urban heat island effect, strict implementation of shaded infrastructure like increased canopy cover, access during extreme weather events could be enhanced.

Considering the above assessment and recommendations, the below table shows an index assigned to each non-motorized transport-SDG interaction at the target level under each scenario (Table V). Each interaction is assessed into synergy (+1), trade-off (-1) or mixed impacts (-/+1). The table shows that the infrastructure in the existing situation show a clear trade-off with access, safety and health; the low carbon mobility scenario shows mixed impacts and the SDG enabled scenario proposed shows synergies.

Table V: Co-Benefits of Non-motorized Transport Infrastructure Improvement in Surat and Udaipur in 3 Scenarios

| | | Existing situation | | | LCMP scenario | | | SDG enabled scenario | | |
|---------|--------------------|--------------------|--------|--------|---------------|--------|--------|----------------------|--------|--------|
| | | Access | Safety | Health | Access | Safety | Health | Access | Safety | Health |
| Surat | NMT network | -1 | -1 | -1 | -/+1 | +1 | +1 | +1 | +1 | +1 |
| | NMT infrastructure | -1 | -1 | -1 | -/+1 | +1 | -/+1 | +1 | +1 | +1 |
| | NMT mode choice | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 |
| Udaipur | NMT network | -1 | -1 | -1 | -/+1 | -/+1 | -/+1 | +1 | +1 | +1 |
| | NMT infrastructure | -1 | -1 | -1 | -/+1 | -/+1 | -/+1 | +1 | +1 | +1 |
| | NMT mode choice | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 |

CONCLUSION

Active transport like walking and cycling promotes healthy lifestyles by increasing physical activity, improving air quality and providing economic independence. Indian cities still depend on these active transportation modes. However, governments and local authorities fail to invest in upgradation of pedestrian and bicycling infrastructure, impacting accessibility, safety and health of individuals and contributing to a decline in non-motorized trips. There are various needs of non-motorized transport users that could leverage the co-benefits of SDGs and low-carbon mobility. Low-income groups spend a high share of their earnings for commuting to work, making them highly dependent on walking, cycling and affordable public transport. These pedestrians and cyclists are captive users who have restricted access to other modes, limiting their sphere of economic opportunities and exacerbating their poverty. The inadequate coverage of footpaths and poorly designed pedestrian crossings all contribute to curbed mobility.

In Surat and Udaipur, almost half of the total trips are by walking or cycling. But, the trip choice of users is slowly shifting to personal motorized modes like two-wheelers and cars, causing an inequitable distribution of road space. Increased urbanization in both cities accompanied with higher household incomes, has led to a steep increase in motorization and 2.5 times increase in traffic levels. Like many Indian cities, Surat and Udaipur have poorly developed and maintained non-motorized transport infrastructure. This insufficient and ill-maintained infrastructure along with high conflict between motorized vehicles and NMT users leads to unsafe street environments. A majority of pedestrians and cyclists in both cities rated the NMT infrastructure as unsatisfactory. With high per capita per year GHG emissions, indirect impacts of poor non-motorized transport manifest various economic challenges.

The Comprehensive Mobility Plan (2046) for Surat and the Low-carbon Comprehensive Mobility Plan (2041) for Udaipur propose sustainable low-carbon solutions to improve active transport and produce co-benefits with access to opportunities, safety and health in both cities. These proposals would improve mobility and access to opportunities to the otherwise “captive users” to a considerable level improving their mode choice. However, in terms of the coverage and the quality of infrastructure, both mobility plans for non-motorized transport have further scope to improve. The fieldwork and the FGDs brought out many additional recommendations to amplify the synergies with SDG targets. Some of them include improving the level of service to 1.0, i.e., the best, proposing all intersections have pedestrian crossings with lane markings, zebra crossings, pedestrian signals and raised platforms to set apart users from motorized traffic; pedestrianizing the walled city or implementing multiple one-way streets for reduced chaos on streets with reliable bus or paratransit service and parking spaces available, tactical urbanism measures to redesign high-conflict intersections with refuge islands, smoother/ flattened turning curves and reduced carriageway widths and increasing the footpath width to 4m around commercial fronts, dense public places. Both cities also have a potential for developing a cycle culture. Hence, it can be enhanced by reducing the urban heat island effect and improving access during extreme weather events with strict implementation of shaded infrastructure like increased canopy cover.

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IN-BETWEEN NATURE: RECONSIDERING DESIGN PRACITCES FOR TERRITORIES-IN-BETWEEN FROM A SOCIAL-ECOLOGICAL PERSPECTIVE

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ABSTRACT

During past decades, Territories in-Between (TiB) have gained increased attention among researchers in the field of urban planning and design. TiB are often considered to be underused, lack spatial quality and are under mounting pressure of urban densification. However, the rich diversity of land uses and abundance of semi-open spaces in the TiB provide unique habitats and social-ecological potentials, different from exclusively urban or rural landscapes. Therefore, urban planners and designers should reconsider conventional planning and design approaches towards these kinds of territories. The objective of this paper is to present a new holistic planning and design approach towards TiB which acknowledges and strengthens these potentials on local and regional scales. The new spatial planning concept that was developed through a 'research-by-design' process, for the particular case of Rotterdam, is called: *The Recovering Membrane*. The Recovering Membrane is defined as a spatial layer of interaction between two distinctive living environments –urban and rural- and various human and non-human actors in them. This research puts forward that design for the TiB should consider the urban fringe as a distinctive kind of TiB with significant potentials for social and ecological development. Moreover, spatial design should strengthen existing spatial qualities of the TiB, to protect its pressured, yet highly valuable, characteristics. Additionally, local nature-based interventions can provide an important tool for placemaking in the TiB, especially when integrated with long-term and large-scale area transformations.

KEYWORDS

Territories in-between; urban fringe; landscape ecology; placemaking; Rotterdam

INTRODUCTION

Ever since the emergence of their disciplines landscape architects and urban designers have been concerned with the distinction between their fields of interest, respectively the rural and urban landscapes. However, because of ongoing urbanisation and sustainability challenges the academic disciplines of urban design and landscape architecture are becoming increasingly intertwined with one another. Moreover, ongoing urban growth and densification in the Netherlands is pressuring semi-open spaces in between cities and rural land [1]. Consequently, the distinction between the urban and rural landscape diffuses [2,3]. To understand the challenges that these semi-urban landscapes are facing researchers are looking for a more nuanced conceptualisation of the prevalent urban-rural dichotomy in spatial planning and design practice. One of the first and most ground-breaking theories that tries to conceptualise and centralise these semi-urban landscapes is Alexander Wandl's research on territories in-between [4]. The concept of TiB is used as an umbrella term to describe dispersed urban settlements which cannot merely be defined as urban nor rural but are somewhere in-between.

Problem field and research question

It is expected that the number of households in the Netherlands will further increase for several decades. This trend is the result of decreasing average household size and ongoing immigration [5]. To meet the housing demand about one million houses have been estimated to be built until 2040. The need is especially high in the larger cities in the Randstad region [6]. The main strategy to allocate these new houses is to transform and densify within the existing urban tissue. Brownfields, infrastructure corridors, old industrial districts, and semi-open spaces along the fringe of the city are key locations for urban redevelopment and new housing projects [7]. These are the typical locations that can be identified as Territories-in-Between [4]. The abundance of unbuilt grey and green spaces in the TiB provides great potential for ecological development and the provisioning of ecosystem services [4,8]. Although the TiB have gained increased attention among researchers, limited attention is given to TiB in planning practices. Consequently, its potential for the provisioning of ecosystem services is often not recognized [4]. Moreover, the TiB are often considered to be underused and lack spatial quality. This wide underestimation of the existing qualities and potentials of TiB among spatial planners and designers is one of the core reasons for the one-dimensional urbanisation processes in the TiB. The densification process in the TiB increases the pressure on urban green spaces and requires urban designers to think of more holistic design strategies that ensure the liveability of both human and non-human species in the TiB. This brings us to the research question that will be answered in this paper: What kind of holistic planning and design approach strengthens the ecological and social potentials of Territories-in-Between, while also taking into account urbanisation needs?

Methodology

The research question is answered through a research-by-design process which is supported by findings from a literature study and spatial analysis of TiB in the Rotterdam region. The city of Rotterdam and its surrounding landscapes were chosen as a case area for the Urban Ecology graduation studio (TU Delft) which this research is part of. The research-by-design process ran parallel to the literature study and spatial analysis. This approach was especially helpful because of the limited available literature on territories in-between. Consequently, the design process helped shaping the theoretical framework of the research. The following section discusses the spatial characteristics and current planning practices in the TiB. Thereafter, the main findings from the literature review are outlined and synthesised into concrete design recommendations for the in-between territories. Finally, the results and insights of the design experiment are presented for the particular case of Rotterdam. The last section of this paper summarizes the main findings and presents design and policy recommendations for professionals in the field of urban planning and design.

TERRITORIES IN-BETWEEN

In academic literature many concepts have been introduced to describe dispersed urban settlements such as peri-urban, urban sprawl, suburban and more [4]. However, these concepts do not sufficiently cover the complexity and diversity of dispersed urbanization patterns. Moreover, Wandl argues that TiB have a distinct character and functioning that cannot be described by a simple urban to rural gradient; based on the dichotomy of urban and rural that most of these concepts rely on [9]. Therefore, he introduced the concept of territory in-between as an umbrella term to describe the significant spatial and functional characteristics of these landscapes. The TiB can be characterized by three prevalent spatial features which distinct the TiB from rural and urban areas: the intermingling of built and unbuilt spaces, the strong functional mix, and the significant presence of infrastructures in the landscape [9].

Social-ecological potentials

The semi-open structure and diversity of land uses in the TiB provides habitats for general as well as endangered species. Species which are more often associated with urban landscapes, but also species which are more associated with the rural landscape. For example, oyster catchers on flat roofed logistic or commercial buildings, common linnet and European goldfinch at brown fields, or the green woodpecker and beech marten at graveyards. Therefore, TiB provide a unique combination and diversity of habitats that differ from merely urban and rural landscapes (Figure 1). Consequently, unique interactions between species takes place that are not seen anywhere else. Additionally, typical land uses like sports fields, allotment gardens and graveyards also provide crucial spaces for people to interact with the natural environment and relieve stress, which contributes significantly to people's well-being [10]. This 'active' interaction between people and their environment is also crucial for building up people's sense of place. Sense of place is an important cultural ecosystem service that will be further explained in the theoretical framework.

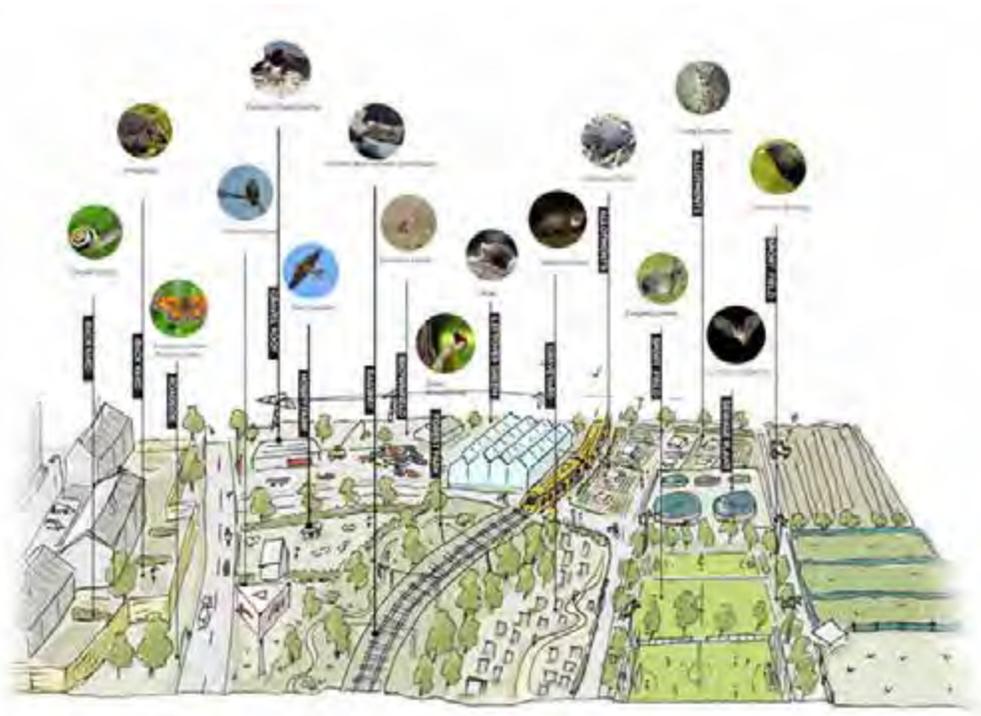


Figure 1: Habitats and species of the territories in-between

Planning practices

In academic literature a consensus exists that dispersed urban settlements are being neglected in spatial planning and policy making. This is even described as one of the key characteristics of the TiB [2,4]. Several socio-economic trends and planning policies are fundamental in the emergence of territories in-between in the Netherlands. First, there is the renowned spatial planning tradition of the Netherlands starting from the 1960's, when the first National Policy Document on Spatial Planning was issued (*Eerste Nota Ruimtelijke Ordening*) by the national government [11]. These national reports outline the spatial planning strategies that need to be implemented by provinces and local governments. The goal of all national spatial planning policies so far has been to control suburbanization and preserve the rural landscape [11,12]. This idea was explained with the use of Dutch concepts like *compacte stad* (compact city), *gebundelde deconcentratie* (bundled deconcentration) and *stadsgewest* (city-region) which were used to give direction to urban growth [2,11]. However, in the last National Spatial Strategy it is argued that national spatial planning policies so far have failed to succeed their main goal of preserving the rural landscape [3,13]. Moreover, they speak of *verrommeling* (cluttering) and spatial degradation of the landscape [14,15]. The prevalent lack of significant landscape features, and the presence of footloose industries and businesses are reasons why many people identify these landscapes as in-authentic and placeless [4,16]. The current densification process taking place in most Dutch cities pushes large scale land uses, such as industrial facilities and sport facilities, towards the urban outskirts. These land-uses are often

re-located along infrastructural routes or at the urban fringe of the city. Moreover, it is expected that the strong emphasis of the national government on economic development in combination with globalization and digitalization trends will put further pressure on the urban fringe of the city [1,11]. Consequently, the TiB will only become a more fundamental part of the Dutch landscape [14]. In 2010, the ministry of VROM was abolished as part of decentralization liberalization measures [17]. Since then, urban development and sustaining spatial quality of the Dutch landscape was no longer a primary task of the national government. The national government concentrated its attention to spatial economic and infrastructural developments [11]. Hence, sustaining the spatial quality within the TiB seems to be an issue of conflict between regional and local planning. A new planning approach for the TiB should therefore provide coherence between developments at the regional and local scale.

The particular case of Rotterdam

The greater Rotterdam area is of particular interest for this kind of study, because of its diffuse urban-rural boundary, the great abundance of in-between territories and the great urbanisation pressure on these areas. Although earlier studies and plans have addressed the densification of Rotterdam's inner-city area [18,19], Rotterdam now aims to build 50,000 new houses until 2040 of which most will be located in existing territories in-between [7]. As a result of the ongoing densification in these territories, the functions and services that they provide are under increasing pressure. This includes allotment gardens, sport complexes and small commercial and industrial districts among others. This is a worrying development, especially because the demand for allotments and outdoor sport facilities has grown significantly during the covid-19 crisis. Spatial data mapping was used as a tool to get a qualitative understanding of the spatial distribution of Rotterdam's TiB and its spatial characteristics in different places, i.e., what typifies Rotterdam's TiB and what makes areas stand out? By overlapping different spatial characteristics of the TiB in a shadow map, it is argued that certain places possess higher degrees of in-betweenness compared to others (Figure 2). The map is composed of four layers:

1. Functional land uses typical to the TiB (industry, sport/recreational land uses and commercial and logistic areas).
2. Large infrastructure corridors.
3. Urban fringes within 200m of built area of city limits.

Degree of protection by environmental policies such as Natura 2000 and Nature Network Netherlands (NNN).



Figure 2: Shadow map of Rotterdam's territories in-between

This map is a first step towards qualitative mapping of TiB. Further improvement is expected to be made with more detailed spatial data analysis on open spaces (Open Space Ratio) and function mix (Mix-use Index) in the area [20,21]. It can be seen that Rotterdam's harbour district, the large green house areas in Westland and the major infrastructure corridors make up a significant amount of the total TiB within the city's surroundings. In order to make a first step towards design-research a theory review is needed to motivate the design choices from a greater theoretical context.

THEORETICAL FRAMEWORK

Previous section already pointed out the important and complex relationship between the spatial characteristics of the TiB and its implications for social and ecological development. Therefore, the three theories that were selected to underpin the research particularly discuss the relationship between these two aspects: *Edge-boundary theory*, *landscape heterogeneity*, and *theory on sense-of-place*.

Edge-boundary theory

This theory is part of Richard Forman's Patch-Corridor-Matrix model. This model is a fundamental research and design model used in the field of landscape ecology [22]. The model describes the arrangement of different spatial landscape elements that together make up the greater landscape structure: the landscape mosaic. According to Forman, the landscape mosaic is composed of three universal types of spatial elements: patches, corridors, and the matrix. The patch-corridor-matrix model can be applied in both anthropogenic and natural environments and at different scales. This makes the model a very effective research- and design tool for spatial planners and designers. Moreover, the model provides a way to compare dissimilar looking landscapes on a landscape structural level [22]. The design of patch edges and boundaries deserves specific attention because their characteristics are of great influence on species migration and human - wildlife interactions. The edge is described as the outer portion of a patch where the environment differs significantly from the interior of the patch. The change of behaviour of species near or in habitat edges is called the edge effect [22]. Territories in-between located at the urban fringes of cities can be considered the spatial edge between the urban and rural landscape with its distinctive edge effects. Because of the continuing expansion of human development into natural environments, spatial edges will increasingly form a critical point of interaction between human-made and natural habitats [23]. Figure 3 shows the relationship between the spatial morphology of the edge and its related edge effects. Urban-rural boundaries which have a high structural diversity, are irregularly shaped and provide a smooth gradient between urban and rural landscapes are essential for species richness, movement, and human-wildlife interactions. In other words, landscape architects and urban designers can re-shape spatial boundaries and influence the ecological functioning of the landscape at macro scale.

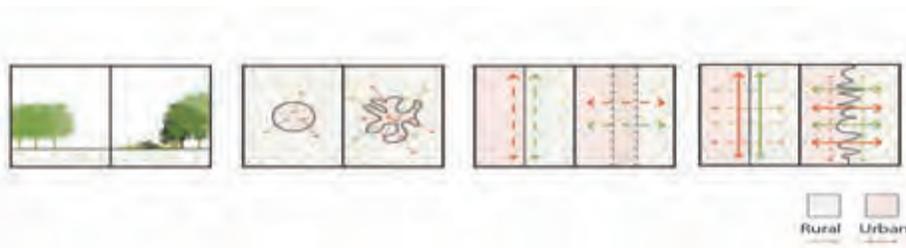


Figure 3: Conceptual representation of patch edges and boundaries, adapted from Dramstad, Olsen and Forman (1996) [23]

Landscape heterogeneity

On a macro level, the mosaic of patches in the landscape can be described by its degree of spatial heterogeneity. The greater the diversity of patches and the greater the spatial mix of them within a specific area, the greater the landscape heterogeneity. Landscape heterogeneity is a fundamental aspect of landscape ecology that aims to relate spatial patterns to processes [24]. Landscape heterogeneity is driven by two aspects: on the one hand the diversity of habitat types (compositional heterogeneity) and on the other hand the size, number, and spatial arrangement of these habitats (configurational heterogeneity). Theoretically speaking, increased compositional heterogeneity leads to more biodiversity because of greater habitat diversity within the territory. Additionally, a greater diversity of land cover types provides complementary resources, such as food, places of refuge and nesting places for different time periods in an organism's life cycle. Greater configurational heterogeneity can also increase biodiversity because of increased connectivity and interspecies interaction [24]. The relationship between landscape heterogeneity and biodiversity is depicted in figure 4. Even though, landscape heterogeneity studies have mainly focused on natural, semi-natural and rural landscapes, the assumption is made that landscape heterogeneity principles can also be applied on more anthropogenic and semi-urban landscapes creating similar results. This theory on landscape heterogeneity is especially relevant for the TiB because of their multifunctional nature and rich diversity in spatial structure at macro level. Figure 5 is a good example of an aerial view of a highly heterogeneous in-between territory along the south border of the city of Rotterdam.

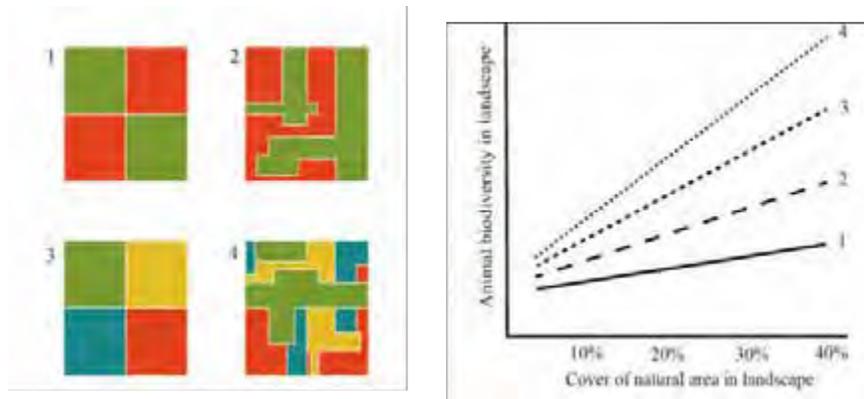


Figure 4: Conceptual representation of spatial heterogeneity patterns (left).
Correlation between spatial heterogeneity patterns and biodiversity (right), adapted from Fahrig et al. (2011) [24]



Figure 5: Areal view of landscape with heterogeneous spatial landscape pattern at the south border of Rotterdam (google earth)

Sense of place

Sense of place can be described as the relationship between people, their imagination, and the physical environment. The concept is rooted in both objective influences of the environment such as landscape design, form, and sensory perceptions (smell, sound, climate etc.) and on the other hand subjective experiences such as memories, emotion, and culture. Therefore, sense of place is a complex concept about the emotional attachment of people to their living environment because of their interaction with the landscape [25,26]. Consequently, facilitating human-nature interaction is essential for the creation of sense of place. According to Canter, a place is created by three main elements: form, function, and meaning [27]. These elements also describe the type of relationships between humans and the environment, respectively, cognitive, behavioural, and emotional. It is argued that good physical form and good function lead to good emotional response (meaning) which results in enhanced sense of place experience. The emotional dimension is therefore a result of the other two dimensions; the behavioural and the cognitive [27]. The heterogeneous spatial structure and the abundance of green open spaces in the TiB provides great potential for people to strengthen their relationship with the natural environment and participate in various kinds of stewardship activities such as restoration, cleaning, and maintenance activities. Actions of stewardship can change people's meanings and attachments over certain places and therefore contribute to people's sense of place [28]. Greater sense of place experience among locals positively influences people's willingness for stewardship activities and can therefore positively influence the ecological quality and performance of the landscape. In turn, greater ecological quality generally provides greater sense of place experience through the provisioning of cultural ecosystem services.

Theory synthesis

The main theory domains that support the design research are the fields of Ecology and Sense of place. Within the domain of ecology specific attention is paid to theory on landscape ecology in relation to biodiversity, i.e. how landscape patterns influence species richness, this includes both the *edge-boundary theory* and the *landscape heterogeneity* theory. The two theory domains are connected with one another through an integrated design approach called ‘nature-based placemaking’. The aim of this approach is to transform spaces into places by integrating not only the needs of the local community in the design process, but also the needs of local nature. It looks at nature as primary tool for placemaking. This approach relies on a positive feedback mechanism through ecosystem services and stewardship and has been of inspiration for the local design proposal (Figure 6).

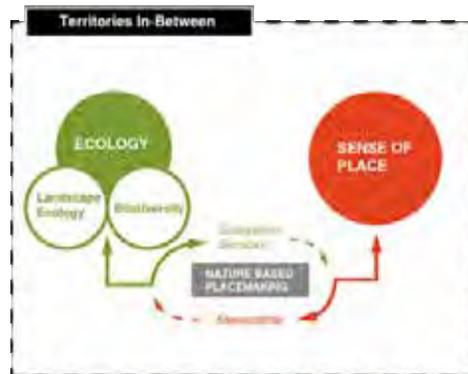


Figure 6: Theoretical framework

DESIGN RESEARCH

This section presents the results of the design experiment. This design consists of four main elements:

1. A regional planning concept and vision.
2. A proposed staged development process.
3. A governing body at sub-regional scale.
4. Transferability study to other regions.

Regional planning vision and concept

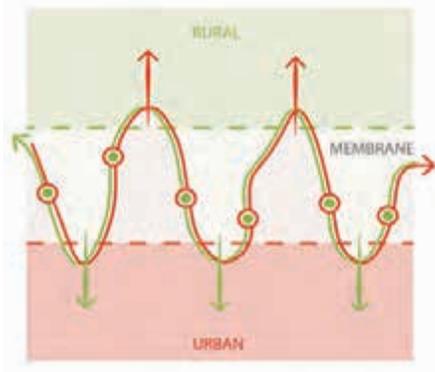


Figure 7: Illustration of membrane concept

Through a research-by-design process, supported by the findings from the literature review and spatial analysis, a new planning approach for the TiB is developed: ‘The Recovering Membrane’. The concept was applied and tested through design research for the case of Rotterdam. The recovering membrane is defined as a spatial layer of interaction between two distinctive living environments –urban and rural- and various human and non-human actors in them (Figure 7 and Figure 8). The membrane aims to bridge the urban-rural divide, enhance biodiversity and sense of place in the in-between territories at the urban fringes of the city. The membrane makes space for the pressured land uses in the territories in-between and strengthens the heterogeneous nature and multifunctionality of the urban fringes of the city. By doing so, the membrane can be considered as a unique kind of landscape with distinctive ecological and recreational qualities which are different from merely urban and rural environments. Moreover, the membrane provides a combination of services that are essential to the city resident’s well-being. Next sections will illustrate the steps towards achieving this ambition at local scale.



Figure 8: Illustration of the Recovering Membrane in the region of Rotterdam

Staged development process



Figure 9: Picture of design area at Kulkweg, Hoek van Holland

The second component of the spatial planning strategy is the staged development process. The spatial transformation of the in-between territory into a membrane landscape can be organised into three development stages: short, medium, and long time. This kind of staged development process allows for a more gradual transformation process. A process which provides coherence between small- and large-scale developments, which creates support among the local community and better respects the existing qualities of landscapes. Next paragraphs discuss the main objectives for each stage in combination with a design impression for a particular case at Hoek van Holland (Figure 9).

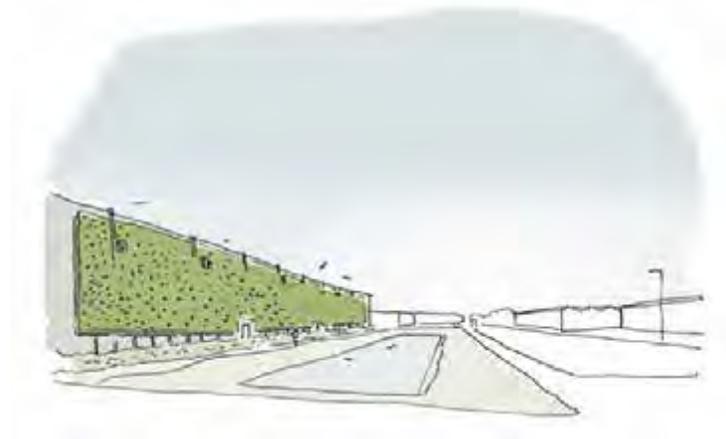


Figure 10: Stage 1, impression of design proposal

Stage 1 (short term, < 5 years): Engagement and activation of the local community through a nature-based placemaking process. The aim of this stage is to improve the spatial quality within the membrane landscape through low cost and short-term interventions in co-creation with the local community. Figure 10 is an impression of a relatively simple short-term nature-based intervention. The sketch shows a green wall with bird nesting boxes mounted on the outside wall of a storage warehouse.



Figure 11: Stage 2, impression of design proposal

Stage 2 (mid-term 5-20 years): Connectivity and integration of the territory in-between within its surroundings through social-ecological corridors. The primary aim of this stage is to improve the social accessibility and ecological connectivity of the landscape to its surroundings. This is especially important for the recreational quality of the membrane landscape that is often very fragmented by large infrastructures. Figure 11 shows how the green facade can become of greater ecological value when connected to an ecological corridor along the waterway and street.



Figure 12: Stage 3, impression of design proposal

Stage 3 (long term, > 20 years) Re-distribution of clustered land-uses to strengthen the heterogeneous nature of TiB. This stage is of specific importance as greater landscape heterogeneity does not only cause greater ecosystem resilience and biodiversity but can also positively contribute to people’s sense of place experience, as has been discussed the previous sections. Figure 12 is an impression of the final situation where some of the greenhouses and large warehouses have made space for a greater diversity of land uses such as a day-care farm, sportsfield and extensive housing developments. This re-distribution of land-uses will further increase the ecological and recreational quality of this landscape.

Governing the membrane



Figure 13: Map of municipalities in which the membrane landscape is located

Existing institutions and partnerships for spatial development at sub-regional level do not sufficiently address the issue of spatial quality of the TiB at the urban fringes of the cities. They seem to be primarily interested in economic development. Therefore, there is an urgency for a distinct governance body that is primarily focused on improving spatial quality at sub-regional level for the territories in-between at this scale. To put this issue on the public agenda and achieve the spatial objectives of the membrane, a new governing body is proposed: The Membrane Management Group. The aim of such a new governing body is to facilitate coordination and cooperation between all municipalities connected to the membrane and ensure spatial quality and coherence of the membrane at sub-regional scale (Figure 13). Interests of local municipalities are represented and together they plan and monitor regional spatial developments in the membrane and ensure consistency between regional- and local-scale projects. By doing so the issue of lack of spatial quality in the TiB is addressed in an integrated way at multiple scales.

Transferability of the membrane

Even though the design approach was developed through a design experiment for the case of Rotterdam the main concept of the membrane is most likely transferable to other urbanised regions and cities. Figure 14 shows the first step of transferability of the membrane concept to other urban regions. The concept can provide urban planners and policy makers with input for urban growth scenarios. A proposed strategy for the monocentric region of Paris is to improve accessibility of the membrane and increase the total membrane surface, in relation to interior urban area, by increasing curvilinearity of the urban border of Paris. A different strategy is proposed for the polycentric region of the Randstad. For the Randstad region the strategy should be focused on protection of the interior (rural) environment, because of the high degree of spatial fragmentation of rural area, resulting from polycentric urban development. In this case a macro membrane landscape for the entire region can act as a buffer for the interior rural landscape, while also connecting different membranes at city level. Therefore, the membrane concept can offer various insights and development scenarios depending on existing spatial conditions at regional scale.

CONCLUSIONS

There is a need for a new holistic planning approach towards TiB which acknowledges the social and ecological potentials of these landscapes. A literature review, spatial analysis of TiB for the case of Rotterdam, and a research-by-design process were conducted to create the newly introduced planning approach: *The Recovering Membrane*. The approach can be described with four key recommendations for practitioners and policy makers in the field of spatial planning and design:

1. Consider the urban fringe of the city as a unique kind of in-between landscape (membrane), because of its ability to bridge the urban-rural divide.
2. Acknowledge and strengthen existing qualities and potentials of the TiB, such as spatial heterogeneity. Spatial heterogeneity provides a reason for mixed land-use development in the TiB.
3. Address issues of spatial quality in the TiB through an integration of different spatial (regional and local) and temporal scales (short- and long-term). Additionally, there is a need for a new governing body that is primarily concerned with spatial quality in the TiB at regional scale.
4. Provide spatial interventions that maximise human-nature interactions increase stewardship and sense of place within the TiB. To do so, nature-based interventions should be used as a primary tool for placemaking in the TiB.

By considering the In-between territories as an integral part of a larger ecological system, the concept of the membrane landscape maximizes its unique potentials for human exploration and wildlife interactions. The design driven research explores what this membrane landscape could look like in order to maximize these human-nature interactions and how these territories can evolve towards achieving this ambition. In addition to the social and ecological potentials that this paper has addressed, further research is recommended on the economic potentials of this introduced membrane landscape. Particularly concerning a future transition towards a more localised economy.

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FUNCTIONAL DIVERSITY IN CIRCULAR BUILDING PROJECTS: A NOVEL PERSPECTIVE TO STUDY ACTORS, ROLES AND CIRCULAR RESULTS

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ABSTRACT

Construction sectors have a long way to go to realize a circular economy. Many organizational barriers and institutional characteristics inhibit the sector's transition to circular practices. Nevertheless, within this early phase of the transition, several building projects were realized. This research aims to learn from these frontrunners, in order to distill insights on how to improve conditions at project level. Drawing on ecological systems metaphor, circular building projects in this research are regarded as a system of multiple actors that each perform one or multiple functions: these functions together make up the functional diversity of circular building project. The sum of these functions produces a system service (i.e. circular building elements). Using this perspective to analyze four circular cases, we uncovered five functions that are crucial to realize circular buildings: 1) connecting though vision; 2) matching supply and demand; 3) providing used materials; 4) constructing circular building elements and 5) controlling safety and quality. The functional diversity perspective reveals that functions are to large extent interchangeable between actors. Further applications of the functional diversity perspective could reveal its relevance to support the transition to a circular construction practice and possibly other transition themes.

KEYWORDS

circular economy; construction; projects; actor analysis; innovation; case study; functional diversity.

INTRODUCTION

The 21st century can be marked by human's reconsideration of the relationship between the fossil-fueled economic system and the planet we inhabit. This is reflected in the enthusiasm surrounding the concept of Circular Economy (CE) over the past 8 to 10 years. Although earlier approaches to the CE exist [1-4], a significant rise in popularity can be recognized recently by the numerous organizations [5] and governments [6] adopting the concept.

One of the sectors in which CE principles can provide considerable environmental gain is the building construction sector [7]. In brief, the transition from a linear to a circular construction sector is aimed at innovations in “the entire chain of production, consumption, distribution and recovery of products and materials” [8], ultimately resulting in a more resource-efficient industry and built environment [9], eventually reducing its carbon footprint [10].

Circular results in the building construction sector

Despite the popularization of the CE concept, the number of constructed building according to circular principles remains small. This situation is caused partly by the building industry-wide institutional characteristics, yet also a variety of more building project related and governance barriers are at play [10-12]. In addition, financial barriers such as the adoption of circular business models [13] and the unproven circular building project business cases [10, 14]. Moreover, segregation of actors involved in different building life-cycle stages seem to be a key cause to prohibiting the realization of circular buildings [15, 16]. Finally, there is discussion going on considering the eco-efficiency and performance of circular products [17] and which to prioritize in the construction sector (e.g. is newly sourced wood better than recycled concrete?). A shared vision on which materials and products should be applied how and where is lacking.

When looking at construction practice, a rise in circular building projects (CBP) can be identified in the past 10 years. These CBP are often small and few in numbers, but none the less crucial for paving the way for institutional change and implementation, by revealing barriers and implications and at the same time realizing more sustainable living environments [6, 18, 19], while fostering innovation in construction [20]. A project-level focus is relevant, as projects form “*the arena where the inevitable process of mutual adaptation of niche and regime take place*”, as stated by van Bueren & Broekmans [21]. Processes of refurbishing, remanufacturing, redistribution and reuse imply new activities for established or new actors, such as demolishers who instead of feeding the recycling industry with used materials, store these materials and deliver them back to contractors for reuse. However, there is not a clear understanding on what actors do to achieve these types of circular results in circular building projects.

Recent research on accelerating the transition to a circular built environment lacks a focus on the project level. Studies focus on identifying enablers and disablers at sector-level [22] or from the perspective of one actor in the building-column [23], what circular strategies for different building life cycles are successful [24] and on stimulating a CE from an inside-company perspective [18]. Literature review by Munaro et al [25] confirms a lack of research regarding actors in CBP and how they achieve results. Scientific insights are usually translated to be useful in contexts such as policy making, sectoral transition management or technical design and tooling. As Pomponi & Moncaster [26] propose: “*the greatest challenges ahead lie not in further technological innovation but rather in the role of people, both as individuals and as a society.*”

Some studies do touch upon roles and activities when looking at how actors aim to achieve specific results in projects. An example is the role of system integrator [20]. The idea of a specific recurring role in different projects provided researchers a tool to monitor what actors in the sector fulfill this role as time progresses (e.g. [27] & [28]). However, to our knowledge, there are no studies that uncover the apparent functions in circular building projects taking all actors into account, in order to uncover how actors achieve (environmental) results. This research focusses on the changing activities of actors in niches of circular construction projects as to: 1) understand how this may be indicative for sector-level transformation (in line with Wittmayer et al. [29]), and; 2) add guidance for practitioners in the field and their daily work as an addition to what niche innovation theory offers.

Defining the environment of circular building projects

The aim of this research is to understand what actors in CBP do and how these roles or activities are crucial to the actualization of circular ambitions on a project level. To be able to grasp the concept of activities and roles in context of circular construction projects, we follow three main lines of thought:

1. CBP's can be seen as a niche in which innovations are nurtured through activities of actors in these projects. The changing activities of for example a demolisher who feeds resources back towards a building project instead of the recycling industry, can be explained through transition theory, as circular construction projects can be considered a niche (i.e. a protective space) in which innovation is nurtured [30, 31]. Niches are typically seen as crucial elements for realizing a transition of sectors or systems, as they provide the seeds for system transformation [32]. Given the multi-actor nature of transition processes, transitions imply changes in the roles of actors and their relations to, and interactions with other actors [29].
2. This research adopts the term 'function' instead of 'role'. We prefer to use the term 'function' because the term intuitively draws attention to what actors *do* rather than *who they are*. This intuitive nuance is important to encourage a focus on changes in actor activities in CBP.
3. To perform functions, actors engage in activities in CBP. There are different theoretical perspectives on actor roles and related activities. Wittmayer et al. [29] derive three main role perspectives: roles as recognizable activity, roles a resource perspective, and roles as boundary object. Our understanding of functions is mostly in line with the first perspective 'roles as recognizable activity'. In line with this perspective, we understand functions as a recognizable set of activities, or in the words of Turner [33] as "comprehensive pattern of behavior and attitudes, constituting a strategy for coping with a recurrent set of situations, which is socially identified – more or less clearly – as an entity".

Summarizing, this research regards CBP as niches in which actors perform functions through engaging in activities as a strategy to cope with situations that emerge as a result of adopting circular principles in CBP. This leads to a framework called 'functional diversity', which we further develop and present in the chapter 'functional diversity framework', which introduces the novel functional diversity perspective (FDP). The methodology chapter describes the research- and data collection method. The chapter 'circular building project cases' introduces the cases studied, while applying the FDP. Chapter 'functional diversity of circular projects' combines the results of the cases studied separately into five functions, including a cross-case analysis. Chapter six discusses the results and limitations and finally the conclusions are presented.

FUNCTIONAL DIVERSITY FRAMEWORK

Drawing on biodiversity- and ecosystems services theory, we develop a functional diversity framework that helps to identify the functions performed by actors in circular building projects. The science of ecology draws our attention due to the vast array of methods [34] used to analyze organism food webs [35] and populations and communities [36]. Network thinking in ecology arose in the early 1940's, with periodic waves of interest. Research focusses on the architecture of networks, network robustness and methods to compare complex networks [37]. Application of ecological concepts to industrial systems is not new and the field of Industrial Ecology is a good example of this. Especially methods of ecological modelling have been mimicked in new ways to study cities and industrial parks [38, 39]. Network theories regarding species have as well been adopted in industrial ecology, used to reveal the interrelation between actors, resources and activities [40, 41]. The named methods are however quite rational in their description of relationships [16], consequentially lacking the detail to uncover how and why certain elements became part of that network in the first place.

The ecology-science concept of functional diversity specifically draws our attention. This concept has been developed in context of ecosystem services [42, 43] and refers to the collection of functions that form an ecosystem which provides an organism with a certain service [44]. Functional diversity offers a way to analyze the biodiversity present in ecosystems by identifying the functional groups that are necessary for the functioning of ecosystems. It has proven to be an efficient way to identify the dependencies in a larger ecosystem that together form the basis to deliver system services [45].

This approach is popular in ecosystems services theory because it is considered key to understanding ecosystem processes, revealing which constellation(s) of species optimally contribute to critical conditions for the functioning of ecosystems and why. Examples are optimizing pollination and production factors, nutrient cycling and resistance to pests [43, 46]. Functional diversity is a way to allocate organisms to functional groups based on their functional traits. These are traits that make an organism compatible to contribute to a function under specific conditions. The concept of functional diversity is introduced in ecology sciences for a similar reason as why it is interesting for the goal of this research: "*Functional diversity generally involves understanding communities and ecosystems based on what organisms do, rather than on their evolutionary history*" [42]. This is in line with the goal of this paper; getting insight into what kind of functions actors perform in CBP, without the pre-assumption of their roles historically observed in projects.

Translation of functional diversity perspective to circular construction projects.

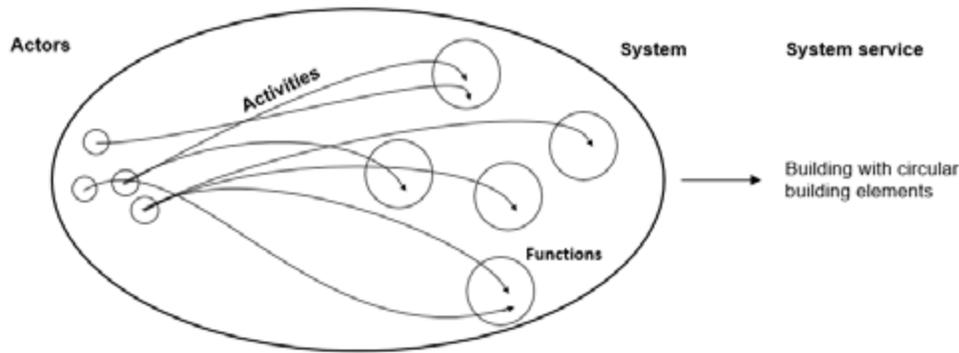


Figure 1: Functional diversity framework for circular building projects. Actors can be linked to one or multiple functions through their activities. The whole of actors and performed functions forms the system that produces the system service: circular buildings.

In this paragraph the FDP is translated to a CBP-compatible functional diversity perspective. This perspective departs from the starting point that a CBP can be seen as a system with a system services, which emerges through functions performed by actors through their activities, as depicted in figure 1.

Similar to a system of organisms, a system of actors can be structured in terms of functions performed. This means that a CBP can be mapped as a system of actors who each perform a function, from which a system service emerges, in this case a building with circular building elements. In this research a framework consisting of four elements is used (figure 1): system service, functions, actors and their activities. This framework is used as a basis for the analysis of cases studies, as described in the following chapters.

METHODOLOGY

We used case studies with a qualitative approach to find out what actors do in CBP. As Yin [47] points out, case study research is a linear but iterative process which enables the researcher to understand a specific phenomenon in all its complexity. Specifically, studying cases by applying the functional diversity framework also allows for cross-case comparison, making sense of similarities and differences, by looking through a conceptual equivalent lens [48]. Four cases were selected, each being completed CBP in the utility construction sector in the Netherlands: a thrift shop in Houten, the Alliander office in Duiven, the Haka building in Rotterdam and lastly the 8th floor of the 100 Watt tower in Amsterdam. The cases are representative for a large part of building projects in Europe, due to their small to medium size and a minimum of at least a commissioner, contractor and architect directly involved with the project. Table 1 provides an overview of the cases studied and their circular building elements.

Table 1: Circular results in the cases studied as system services

| | Remanufacturing | Reuse/redistribute |
|-------------------------------------|---|---------------------------------|
| Thrift store, Houten | Wooden façade covering from dismantled pallets | Concrete slabs as façade |
| HAKA building, Rotterdam | Partition walls from clothing, furniture out of remanufactured wood | - |
| Alliander office, Duiven | Wooden façade- coverings from dismantled pallets | Reused toilets and furniture |
| 8th floor 100 Watt tower, Amsterdam | Partition walls harvested from a donor building | Reused carpet, reused furniture |

Data collection

Data were collected through a total of 8 interviews (two actors interviewed per case) and an expert-panel to evaluate the results of the interviews. Interviews were conducted with actors who had a prominent role in the cases and who were involved in at least the initiation, design and construction phase of the project. The interviews were recorded and the recordings were stored. Photos of post-it's used to make an inventory of the activities during the research were made in order to reproduce the data for the analysis. A summary of the interview was sent to the interviewees afterwards to confirm the results. In this research, actors can be interpreted mainly as a group of people affiliated with the case through the organization they work for. Project managers however are represented by one person in the cases, since this role is typically executed by one person. The system boundaries were maintained by identifying organizations that were directly involved in the project or because they represented a link in the supply chain of circular building elements. In order to structure the interviews, the backward analysis approach [49] was used. This approach is used in case studies to uncover sequences of cause and effect prior to a specific outcome of interest. This leads to the following interview structure.

1. *Introduction:* the interviewee was asked about his/her involvement with the project, the activities (s)he performed and when (s)he got involved.
2. *System services identification:* the interviewee was asked to summarize the circular building elements which were realized in the project. The elements were written on post-its.
3. *Actor-system identification:* the interviewee was asked to write down the name of each actor which (s)he regards to be crucial for the realization of the circular building element on a post-it. These post-it's with actors were placed next to the post-it's with the corresponding system service.
4. *Activities identification:* under each name that was written on a post-it in step 3, the interviewee was asked to indicate what made the actor crucial to the process. This could be anything, from a certain skill, action, to a specific technology (s)he used.

Data analysis

Specifically interesting in the data analysis of different cases, is that comparable behavior and patterns can be extracted, in turn enabling the identification of recurring case study mechanisms [50]. Following this approach, the data were analyzed through the following steps:

1. *Make an inventory:* list the system services for each case;
2. *Map actors and activities:* list actors and their activities related to a system service of each case separately;
3. *group activities from different cases in a cross case overview:* The activities observed in the different cases were matched through identification of the nature of the activity: what was the actor aiming to achieve?;
4. *Analyze groups:* in keywords, name the essence of each group of activities according to what these actors aim to achieve.
5. *Establish functional diversity:* list the keywords of each group in order to review the results. If necessary, optimize words in order to completely cover the observed activities.

In order to validate the results of the interviews, a panel with six practitioners in CBP was organized. In order to stimulate impartiality, the practitioners were not directly involved in the cases. To make sure enough expertise was present, the experts were required to have personal experience in CBP. The expert session was based on Quist's (2007) interactive back casting study method, step 1 to 3 specifically.

CIRCULAR BUILDING PROJECT CASES

This section presents and describes the four CBP cases. Each case is summarized, followed by an inventory of the actors and their activities that contributed to the system services apparent in the case and are shown in tables 2 – 5. The activities are listed in chronological order.

Thrift store, Houten

The municipality of Houten aimed to develop a new thrift store. Through a procurement process, in which “vision on sustainability” was one of the selection-criteria, the market was challenged. Engineering & consultancy bureau Arcadis won the tender, because they were considered to have a convincing vision on sustainability and the lowest price for the development of the building. Arcadis served as project manager, advisor and architect, responsible for cost calculation, quality and design. They formed a consortium with a combination of contractors van Bekkum and De Zeeuw. Table 2 provides the significant activities that contributed to the system service.

Table 2: Actors and activities collected in the interview during the Thrift store case study, resulting in the system service of reused wood for façade cladding

| Actor | Activity |
|---|---|
| Municipality (Commissioner) | Setting “Vision on sustainability” as a selection-criterion for the procurement of the project. |
| Architect and project manager | Developing a convincing vision on sustainability, combined with a low price for the development of the building. |
| Architect, project manager and municipality | Looking for materials to reuse in the surroundings of the building site, through online search engines or by looking for other projects owned by the municipality from which materials can be reused. A company called ‘Triade’ was found through an online search, who offered used wooden boarding. |
| Triade | Collecting old wooden pallets, removing nails, storing them and putting them up for sale online as reusable wooden boards. |
| Architect | Consequentially to the decision to reuse the wood, the architect had to adjust the design of the façade based on the measurement of the used wood. |
| Municipality (as property manager) and project manager. | With the reuse of wood, chances are that some of the facade may require maintenance earlier compared to newly produced wooden boards. The project manager discussed this in an early stage with the municipality. Due to the ambitions of the municipality’s aldermen and property manager that match the project managers vision, they accepted this as an investment that is worth realizing a circular facade. |
| Materials specialist | Reusing wood from pallets results in uncertainties regarding fire safety and being heavy rainfall-proof. A materials-specialist was involved, who could advise on quality standards concerning climate and safety. This gave the commissioner confidence in the circular facade. |
| Contractor | Mounting the used wood to the facade required many hours of labor. Finding people with a distance to the job market (thus a low hourly rate) for the preparation and mounting of the wood to the façade was necessary to avoid exceeding the budget. |
| Workers with a distance to the job market | Cutting wooden boards into correct size and mounting them to the façade under supervision of the contractor. |

Alliander office, Duiven

Alliander, a Dutch gas and electricity infrastructure network operator, occupied an office in Duiven that was considered outdated. The organization needed an office that could accommodate its growth. For the redevelopment of their office, Alliander had put “quality of the vision” of the applicants as one of the central selection criteria in the procurement. Applicants were not only selected on price and quality but were additionally asked to explain how they could contribute to reusing materials and other sustainable solutions in face to face interviews. The winning consortium was a team of architect RAU and contractor Boele & van Eesteren (amongst others). Table 3 lists the significant activities that contributed to the system service. Advisor Copper8 was responsible for the strategic commissioning of the project in collaboration with Alliander. For the further execution of the project, Alliander delivered a project manager from their own organization, who worked together with counterparts from the architect and contractor.

Table 3: Actors and activities collected in the interview during the Alliander office case study, leading to the system service of reused wood as a façade cladding.

| Actor | Activity |
|--|---|
| Advisor and Commissioner | Setting 'quality of the vision' as an important selection criterion for the procurement. |
| Contractor and architect | Writing a winning vision on reusing materials, with the outstanding ambition that 80% of the used materials are to be reused. |
| Project manager | First step of the project manager was to generate as many ideas for reusing materials as possible. Workshops with Alliander employees generated ideas for materials to reuse. One idea was executed: reusing workers clothing as insulation material. |
| Project manager | From the workshop many ideas were collected, however only one was feasible which was not enough to meet the 80% reuse-ambition. The project manager had to look for more sources of reused material. A waste-processor that was located near the office was asked for an inventory of materials they obtain weekly. This uncovered that a substantial amount of wooden pallets passes through the waste processes that could be reused. |
| Architect | At the same time, the architect was performing studies on possible materials to reuse and how to apply them in a design |
| Contractor | A team of people with a distance to the job market (i.e. low hourly rate) was initiated to dismantle pallets for a lower hourly rate than the contractor could deliver with own personnel. Also, storing the pallets on the construction site turned out to be important. |
| Contractor and workers with a distance to the job market | The workers were cutting pallets into correct sizes applicable for façade covering, under supervision of someone from the contractor. Afterwards the contractor processed the used wood as façade cladding and mounted them to the building. |
| Project manager | It turned out to be crucial to involve the fire department early in the process to gain their willingness to collaborate on the project, instead of consulting them at the latest moment. It was foreseen that the contractor could not prove sufficient fire safety of the reused wood without a test. |
| Safety advisor | An advisor was hired that made mockups of the façade, set them on fire and concluded that the wood was safe to use. |

HAKA building, Rotterdam

Real estate developer Vestia acquired the HAKA building in Rotterdam, to redevelop it into a mixed-function building. Their aim was to gain a prominent position as real estate developer in the area by renovating this monument into a sustainable icon. Because the HAKA building is a monument, reuse of materials was a central theme to the project from the beginning, in order to retain the heritage value. This resulted in the vision to also re-use as much materials as possible for new building elements that had to be added to the building. Table 4 presents the activities necessary for realizing the system service.

Table 4: Actors and activities collected in the interview during the HAKA building case study, leading to the system service of reused wood for a stage and reused clothing for a partition wall.

| Actor | Activity |
|-------------------------------|--|
| Project manager and architect | Setting the ambition of the building as an 'icon for sustainable development', by means of reusing materials found in the near vicinity of the building. |
| Architect | Searching for materials to reuse, the architect stumbled upon a nearby second-hand clothing collecting facility. A large pile of clothing disapproved for reuse was donated for use for the HAKA building. |
| Project manager | For applications such as a podium and partition walls, Vestia's project manager started contacting colleagues who were working on projects scattered around the city. This resulted in the harvest of reusable wood. |
| Waste processor | The two waste processors involved with the projects providing the wood, stored the materials temporarily on their terrain until the project manager organized transport of the materials to the HAKA building. |

| | |
|---|--|
| Project manager & specialist supervisor | Assembling the materials to produce the building elements designed by the architect proved to be too expensive if the work was done by the already hired contractor. The project manager found an organization which helps law-offenders with reintegration in society after their sentence has passed. A team was assembled to process the harvested materials into building elements. Intensive supervision was necessary to make sure the team could construct the building elements, for which a specialist construction supervisor was hired. Together they assembled several partition walls and a podium. |
| Architect | Designing a partition wall from reused clothing and wood and designing a podium from reused wood, including instruction manuals for the team of workers how to mount the building elements. |
| Project manager | Few weeks before date of completion, the interior elements were tested for fire safety. The fire department was very concerned about the partition wall's fire safety due to the use of clothing. The project manager ensured fire safety by hiring a specialist company, in order to impregnate the wall with a fire retardant. This cost extra time because the separation wall had to be dismantled in order to properly impregnate the material. |

8th floor 100 watt tower, Amsterdam

Copper8 is a Dutch advisory company focusing on circular economy and sustainable development. As their organization grew, suitable office space was needed. They found a suitable office, however the floor they would occupy needed a retrofit. Copper8 decided that the retrofit should be in line with their ideas on circular economy. The significant activities in table 5 were found crucial to the realization of system services. Due to the fact that no structural adjustments to the building were made, no extensive fire-safety control was necessary.

Table 5: Actors and activities collected in the case during the 100Watt tower case study, leading to the system service of reused partition walls to divide the office floor into meeting rooms and working spaces.

| Actor | Activity |
|----------------------------------|--|
| Commissioner and project manager | The project manager of Copper8 had to convince the property owner of their circular vision. The property owner acts as commissioner since they are the ones investing in their own building by request of the new tenant. It took some effort but in the end the commissioner was convinced and adopted the vision and proposed business case. |
| Architect | The architect started looking for materials to reuse, mainly through online search engines. The biggest breakthrough in finding reusable material however was done by the intern of the architect who rode his bike through Amsterdam, visiting construction projects and looking for materials to reuse. A project where used glass partition walls were discarded was found. |
| Commissioner and waste processor | Searching for reusable materials from other buildings in property of the commissioner. Also, the commissioner made effort negotiating with the hired demolisher about the price for reuse, storage and delivery of the glass partition walls. |
| Contractor | A carpenter was hired as a contractor, who was able to make adjustments to the glass partition walls in order for them to be installed. Since it was a fairly small project, this one-person contractor could handle the project. His tariff is lower than that of hiring an organization which proved necessary to not exceed budget. |

FUNCTIONAL DIVERSITY OF CIRCULAR PROJECTS

This section is the result of steps 3 to 5 of the data analysis (see Section 3) in order to distill generic functions performed in circular building processes. Activities were compared and coded according to similarities, resulting in groups of activities. For example; interviews brought forward activities such as “intern riding a bicycle through Amsterdam looking for materials”, “Project manager searching for reusable wood through online search engines”, “Architect visiting second hand clothing depot in the nearby harbor” and “Project manager contacting nearby waste processor inquiring for reusable material”. The similarity is that in all these activities, actors were looking for ways to find a supply of circular material for the demand of the project. Thus, the function ‘Matching supply and demand’ was distilled.

In total, five functions were distilled that occurred in each of the cases. These functions appeared to be crucial to CBP: Connecting through vision, Matching supply and demand, Providing used materials, Constructing products and building elements and Controlling safety and quality. The functions are described below. We summarize the nature of the function, who performed the function, and the recognizable set of activities, followed by a cross-case overview of which actor performed which function.

Function 1: Connecting through vision

This function entails establishing a vision. Actors who are involved with creating the vision, believe in the vision and agree upon pursuing it. In each of the case, a shared vision set in the beginning of the project turned out to be crucial. An important moment to set a vision is when a consortium is formed that will design and build the project; this is the moment to collectively agree upon the ambition to adopt circular principles and to what extent. Also setting the rules of the game is an important activity (for example in the tender procedure) and setting a business case that involved parties could agree upon. Characteristics like enthusiasm, being highly driven, and being able to inspire people are important to perform these activities and thus the function. For example; the Vestia project manager who co-created the vision for reuse and sustainability for the HAKA building was a charismatic man who also repairs old cars as a hobby; this inspired others to realize a circular building.

Function 2: Matching supply and demand

The search for reusable materials that fit with the project-vision is recognizable in each case. Actors aim to expand the search for reusable materials geographically (e.g. visiting demolition projects in the vicinity) or within their own organizations by use of online search engines and workshops. This function is easier to perform by actors who own multiple properties, have access to online search engines and have the time and money to visit organizations that handle used materials such as waste processors.

Function 3: Providing used materials

Physically selecting, storing and moving used materials from A to B is necessary in order to construct circular buildings. This includes being able to separate usable materials from non-usable ones. Temporary storage space is necessary, since the moment of installing the materials in a building always differs from the moment the materials are harvested. When a waste processor is actively contracted on a project to demolish a building, persuasion was necessary in order to convince the waste processors to separate these materials from waste streams and store them onsite. This is due to the fact that part of their ‘business’ is being taken to reuse. In the cases where a waste processor is asked what materials they still have on their terrain, they proved to be cooperative since these are reusable materials but sometimes too specific in size or other characteristics, making the materials difficult to sell to most customers.

Function 4: Constructing products and building elements

This function entails the construction of usable products and building elements from used materials. Since the used products usually do not fit the design of the building, they have to be processed in order to apply them as building elements. In all cases studied, regular construction workers delivered by contractors were over-qualified (i.e. too costly) for this work. Thus, alternatives had to be found. In three of the four cases people with a distance to the job market were found. In the cases where people with a distance to the job market worked, supervision by an experienced person was necessary. Being creative in how to use unconventional products and remanufacture them into building elements is necessary. For example knowing how the old doors are used in partition walls in the HAKA building, or how the old window frames are reconstructed as partition walls in the 100Watt tower.

Function 5: Controlling safety and quality

Ensuring the quality and safety of buildings when materials are reused is dominantly present in CBP. It takes extra effort to ensure the quality and safety of used materials compared to the use of virgin materials. In the end, the authorities and the commissioner and/or property manager have to agree with the chosen materials and its specifications, for example requiring more maintenance than virgin materials require. In cases where this risk had been mitigated early, unforeseen situations later in the construction process are avoided. For example by involving the fire department in the design phase in the case of Alliander, fire safety was ensured during the process, contrary to the HAKA case where the fire department was involved in a later stage and ensuring fire safety put the planned delivery date of the building in danger. Table 6 presents a cross-case perspective to which actors contributed to what functions:

Table 6: Cross case overview of functions performed by which actors

| Thrift store Houten | Alliander office, Duiven | Haka building, Rotterdam | 8 th Floor 100 Watt tower |
|--|--|---|--------------------------------------|
| Connecting through vision | | | |
| Architect Commissioner Contractor Project manager | Architect Commissioner Contractor Project manager | Architect Commissioner Municipality | Commissioner Project manager |
| Matching supply and demand | | | |
| Architect Commissioner Project manager | Architect Commissioner Project manager | Architect Commissioner Project manager | Commissioner Project manager |
| Providing used materials | | | |
| Contractor Waste processor | Contractor Employees Alliander Waste processor | Waste processor | Waste processor |
| Constructing products and building elements | | | |
| Contractor People with a distance to the job-market | Contractor People with a distance to the job-market | Supervisor (hired by project manager) People with a distance to the job-market | Contractor |
| Controlling safety and quality | | | |
| Project manager External advisor Municipality | Project manager External advisor Municipality | Project manager Municipality | Project manager |

The following patterns can be seen when looking at the cross-case functional perspective:

- In two cases, the contractor was involved with the function ‘connecting through vision’. In these cases, the contractor also proved to pro-actively contribute to the function of ‘matching supply and demand’. In the latter two cases, the contractor was not directly involved in creating a vision, which also proved to reduce contribution to the matching supply and demand function. This suggests that involving the contractor in this function can be helpful in finding materials to reuse.
- Involving authorities such as the municipality and fire department in an early stage, can drastically reduce costs and time spent on the process of ‘ensuring safety and quality’, in terms of not having to deal with unforeseen barriers in later stages of the construction process. In two cases this was apparent while one case brought forward a significant delay in the project due to not involving authorities in certain design choices.
- The commissioner of the projects is an important actor to the function ‘matching supply & demand’. This is due to the fact that the commissioner is involved in establishing the vision to the project and because they are part of an organization owning real estate and thus potential resources.
- Labor costs proved to be decisive for the type of labor used for the circular building elements. Three out of four cases involved people with a distance to the job market. All cases brought forward that supervision is extremely important when working with groups like these.

DISCUSSION & LIMITATIONS

This research aims to provide insight into how actors achieve circular results in CBP, in spite of all the barriers that prevent a transition to a circular economy. We argue that the project-level and how actors achieve circular results is underexposed in research concerning the transition to a circular building and construction sector. Resulting in a lack of guidance for practitioners to increase circular results. Thus, novel perspectives to unravel the way these results are achieved in projects are paramount. The functional diversity concept serves as a way to unravel how actors achieve circular building results. Hereinafter we discuss the results of applying the functional diversity framework and its effectiveness to understand the matter.

Most importantly, the cases show a high degree of improvisation performed by actors to fulfill the functions. This can be interpreted as a positive signal to practitioners that circular results can be achieved, even in a linear construction sector with the transition far from being there. This improvisation is the result of the immature market for materials to reuse, which forces actors to improvise by searching the internet, organizations or the surroundings of a project to be able to ‘match supply and demand’. Or hiring advisors to test refurbished building elements on fire safety. This improvisation can be straining: architects and project managers spend their evenings searching for materials online, or contractors tasked with sourcing alternative types of labor. The cases indicate that a strong vision with clear ambitions for the project established by at least an intrinsically motivated commissioner, architect and ideally also a contractor, fuels the effort to improvise and in the end succeed.

That being said, this study also alarmingly shows how far the construction sector is from being circular. The mentioned barriers negatively affect the CBP: To reach circular results, it requires the scarce intrinsic motivation and leadership of individuals to maneuver around obstacles, thus making painfully clear how fragile the circular practice currently is and that if this remains the norm, a transition in the Dutch construction sector will not take place. Until then, we advise practitioners to be conscious to the required functions for CBP and to be willing to accept that improvisation is needed to achieve results.

The question remains, does the FDP produce novel results? The importance of establishing a vision has been identified as key for sustainable transformation in previous studies [51, 52]. Leising et al. [16] also find this more specifically for CBP. However, with the functional diversity framework we were able to uncover also other key functions (such as controlling quality and safety and constructing circular building products and elements) and what traits made actors suitable to perform these functions. This shows that the FDP is a valuable addition to the conceptual toolbox of researchers and practitioners interested in steering towards circular building practices.

Limitations

To our knowledge, this is the first time the concept of functional diversity is translated and applied outside of ecological sciences. A limitation to our study is a lack of comparable studies to be able to reflect on the gathered data and outcomes. This is greatly needed to assess the true potential of the FDP: would a different perspective reveal a more representative constellation of actors? Second, a limitation is imposed though the choice of cases, which can be regarded as medium size and even small. Large scale projects, in their complexity, tend to rely more on standardised processes and norms, forming a different type of niche. One can question what functions would be uncovered in comparison to the cases in this research. Third, it would be interesting to apply the FDP to the same company, operating two different CBP. This would add insights by revealing what factors could be accounted to the specific actor involved, or the project setting in general. Finally, our starting point was to obtain qualitative results about what actors do in CBP, contrary to the mostly quantitative use of the functional diversity framework in ecology sciences, e.g. to establish richness, evenness and divergence [53]. In that sense, this research did not yet benefit from the full potential of the functional diversity framework. It would be interesting to greatly increase the number of projects viewed through the lens of functional diversity, in order to establish the diversity terms of evenness, divergence, etc., gaining a rich understanding of functional diversity at the construction sector level.

CONCLUSIONS

The aim of this paper was to gain understanding of what actors do to achieve results in CBP. The functional diversity perspective was developed to distill generic functions from four cases of CBP and to explore the use of such a novel perspective. Five functions were found that were dominantly present in each of the cases: Connecting through vision, Matching supply and demand, Providing used materials, Constructing products and building elements and Controlling safety and quality. We found that the functional diversity perspective, 1) allows researchers to reveal the essence of the contribution of different actors related to a system service (in this case circular building elements) and 2), configure new constellations of actors and their roles and a useful perspective to unravel the dynamics of circular economy in the construction sector. We thank the practitioners for participating in the interviews. This study is published after consent of the gathered data is given by the interviewed practitioners. We thank the experts who contributed to the expert panel. This research did not receive any specific grant.

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CORRELATION BETWEEN TRANSIT USE, POLLUTION IN MAJOR CITIES

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ABSTRACT

Due to our planet's consistently increasing population, there are not many solutions to the large percentage of pollution occurring from motor vehicles. One of the many reasons for this is that traffic growth data is challenging to process and manage. After detailed research on the current issues regarding public and private transportation in major cities around the world and their effect on our environment, this study aims to create an adaptive computer model that can give insights and allow us to establish new procedures and protocols to achieve Net-Zero carbon emissions. The model that we created will fetch important data regarding traffic patterns, volume, emissions, and other factors such as Electric Vehicles' growing popularity. It will then analyze and discover the crucial features that will help identify critical problems in the areas of transportation that need to be dealt with in the first place. It will also display the correlation between traffic growth and increased air pollution in our cities. Finally, data will be fully visualized to provide fast access and easy comparison between various solutions.

KEYWORDS

INTRODUCTION

With the development of urban areas and the growth of roads and road use, either in public transit or in personal transit, an increase in air pollution comes with it. Many articles cover how greater increases in use of public transit bring down pollution however it is shown that public transit replacing personal transit has limited success in affecting air pollution [1]. The limited success can be largely attributed to the increase in produced pollution from public transit and the higher rate pollution is emitted [4]. In comparison to this idea that increasing public transit won't have much affect, the idea of eco-driving and managing vehicle speeds proposes that it is not the vehicles but how they drive that really matters [2]. This creates a separation between those who believe that shifting to public transit will create a better environment through the removal of cars and those that believe the better utilization of cars will lead to a healthy world.

This difference between the two kinds of transit doesn't mean there aren't benefits to both. Public transit is generally a cheaper option while private transit options are something a person has greater control of. The lower cost of public transit however does not guarantee its use or increase of use and has declined in the areas of Los Angeles [5]. Public transit is also much easier to access in central parts of urban areas and harder to access in suburban areas which can factor greatly into use [7]. Looking to the future however it is shown and continually predicted that people will move into cities more [8] which does lend to the idea that public transport will be in greater and greater use with private transport on the decline.

This movement towards cities also involves populations living in denser areas closer to roads than in more suburban areas, this can create health issues as the proximity to air pollution produced in these areas by things like transportation can have a large impact on health [3]. Against this idea however there has been evidence put forward that there isn't an increase in issues like childhood cancer when children live by traffic-related air pollution in pregnancy and early life [9]. Studies targeting traffic police directly exposed to a large volume of emissions daily have however reported decreases in lung function, other illnesses however have conflicting results [10].

Traffic congestion is a significant factor to take into consideration when calculating CO₂ emissions from vehicles. When a vehicle's speed falls below 45mph, CO₂ emissions significantly increase. Inconsistent and varying speeds almost always cause the most emissions from traffic [6]. Increased traffic congestion is rarely inevitable with population increase and more vehicles on the road. There are traffic smoothing strategies such as creating variable speed limits that can allow drivers to maintain consistent speeds, but these prevention tactics do little if not properly implemented.

With these contrasting arguments of what truly produces a more effective change in air quality, one of our goals is to examine data from public city API's and examine their validity of having a correlation between transit use, pollution, and socio-economic status. The data that we pull from public city API's include traffic volume at certain time intervals during the day, transit routes and their subjective volume, emissions and pollutants, and EV sales per capita in major urban cities. For this study we decided to specifically target major North American cities with differing volumes in transportation methods which includes public and private transport.

RELATED WORKS

We could not find any directly related works that cover the same material, but we do describe the works that inspired this concept in our introduction.

PROBLEM STATEMENT

Finding a connection between socio-economic status, pollution, transport, and health is quite difficult as there are many separate data points for each subject but nothing that easily binds them together. We currently know that data leans both ways in that different methods of transport both have been shown to create issues and not create issues. We know that there is greater levels of pollution in high transport areas, and we know that socio-economic status can be predictor for health issues. We want to specifically see if we can find out if people of lower socio-economic status are more prone to health issues near places of high transport compared to further away from places of high transport. This area is a clear issue as large populations of people from lower socio-economic status tend to live near areas with large amounts of transport and as such this affects many people. If this paper finds a connection then the algorithm produced by it could be a valuable tool to use to judge if one should move to an area of high transport or not if they are already at risk of health issues. This will allow for a better choice for people in the future

concerning their health if they have the option to choose where they live. What we hope to find out at the end and be able to use is the correlation between location, income, and health, and an algorithm that can process input values from different cities to judge the safety and overall healthiness of an area.

ALGORITHM DESCRIPTION

For our study we utilized csv files from the cities of Seattle, Los Angeles, and New York that focused on health, pollution, socio-economic status, and transportation. By using these files and comparing the values within them against each other we hope to find a definitive value we can use to judge areas based on these subjects. We used the Pearson correlation coefficient to denote the strength of the relationship between multiple variables. Its formula is depicted by the image below. We applied the Pearson coefficient to create the correlation matrix using the Pandas module in Python, and visualize the correlation matrix using SeaBorn and Matplotlib.

$$\rho(X, Y) = \frac{E[(X - \mu_X)(Y - \mu_Y)]}{\sigma_X \sigma_Y} \quad (\text{Eq. 1})$$

Pearson's coefficient is defined as the expected sum of two values minus their averages, times each other, over the standard deviation of both values. We plug the traffic volumes and the particles of pollution in the air from out two cities into the correlation and that creates our end result.

SIM SETUP

Our idea was implemented inside Visual Studio Code using Python, with a main.py file focused on processing the data we had stored for it. We found the data from city API's and downloading csv files containing said data, which we had to reverse-geocode the location data in the csv's as they contained different information that could not be traditionally cross-referenced. We used Google's Geocoding API, which provided coordinates as well as address details for each query in a nested Python dictionary. For the specific range of each location we used, we chose a mile as a good point of value to separate them by, or more specifically a different of 0.1 degrees between the two locations. Some data had to be left out because of errors or lack of reporting with it, so some locations are less accurate than others.

The Pandas library in Python allows programmers to handle data in the form of dataframes imported from csv files. Through this method we sent the csv data to be parsed in our Python program. Pandas was used on multiple occasions for inserting column data and also writing to new csv files meant to duplicate the original data but also include the correctly geocoded data so as to easily reference it without compromising the original data. We were able to cross reference air quality data locations and traffic volume for New York as well as Los Angeles.

Correlation matrices were pulled from Pandas and then a visual representation was created with Seaplot and Matplot Library. The representation is a box with an X axis representing air quality and a Y axis representing traffic volume, with the correlations in between. Ones are expected where the data overlaps but the areas where it is not the number one produce our main findings.

```
"""Create dataframes for both LA Traffic Volume and Air Quality using Pandas """
# Use coordinates and total 24 hr volume columns from Traffic
df_traffic = pd.read_csv("LA_Traffic_Volume_With_Coordinates.csv")
data_we_want["coordinates"] = df_traffic["coordinates"]
data_we_want["volume"] = df_traffic["24 Hr. Total Vol."]

# Use coordinates and PM 2.5 particle count columns from Air Quality
df_air = pd.read_csv("Air_Quality_LA.csv")
data_we_want["count"] = df_air["Count"]

data_we_want["Location"] = df_air["Location"]
```

Fig. 1. Create dataframes for both LA Traffic Volume and Air Quality using Pandas

```

class_enough = {}
particle_and_traffic = {}
particle_and_traffic["particles"] = {}
particle_and_traffic["traffic"] = {}
air_index = 0
# For each borough we try for air quality, we include this value as a separate variable (instead of using just the air_index)
# Adding
for location in data_we_want["location"]:
    location = location.strip()
    location_list = location.split(",")

    loc_lat = float(location_list[0])
    loc_long = float(location_list[1])
    class_enough[location] = {}, {}
    class_enough[location].append(float(data_we_want["count"]*air_index))
    particle_and_traffic["particles"].append(float(data_we_want["count"]*air_index))
    traffic_index = 0
    for coordinate in data_we_want["coordinates"]:

        try:
            coordinates_list = coordinate.split(",")
            coord_lat = float(coordinates_list[0])
            coord_long = float(coordinates_list[1])

            if coord_lat == loc_lat or (coord_lat - loc_lat + 0.01) <= coord_lat <= (loc_lat - 0.01):
                class_enough[location][1].append(float(data_we_want["count"]*traffic_index))

            traffic_index += 1
        except:
            traffic_index += 1
    total = sum(class_enough[location][1])
    particle_and_traffic["traffic"].append(float(total))
    class_enough[location][1] = total
    air_index += 1

```

Fig. 2. Grouping traffic volumes by street for LA.

```

part_and_traffic_df = pd.DataFrame(particle_and_traffic, columns = ["particles", "traffic"])
corrMatrix = part_and_traffic_df.corr()
sn.heatmap(corrMatrix, annot = True)
plt.show()

```

Fig. 3. Displays the correlation results after collecting the data for both LA traffic volumes and air pollution.

```

def google_geo_finder(FILENAMES = "idk"):

    all_addresses = []
    gmaps = googlemaps.Client(key = 'API_KEY')
    df = pd.read_csv("Traffic NY Update.csv")
    for location in df["Spec Boroughs"] + " New York":
        count = 0
        try:
            print(location)
            geocode_result = gmaps.geocode(location)
            result_we_want = geocode_result.pop()
            address_components = result_we_want["address_components"]
            formatted_address = result_we_want["formatted_address"]
            if "Manhattan" in location:
                if count == 0:
                    all_addresses.append("Manhattan")
                    print("Manhattan")
                    count += 1

```

Fig. 4. Groups data by boroughs as streets was not an option for New York.

RESULTS

As for the results we found, they aren't what we expected showing a moderate correlation if any between the traffic volumes and air quality in the two cities. From the method we used and taking the city's different years of traffic and pollution, there were only a few that would lead to believe high traffic causes high air pollution. Our correlations on average were below .5 with some outliers that don't exactly prove there is greater than a moderate correlation



Fig. 5. 2014 New York

Our strongest standard correlation, which is strong when compared to the rest but is on its own, a moderate correlation.

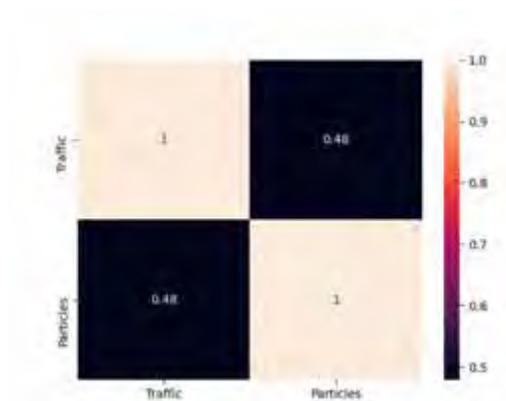


Fig. 6. 2015 New York

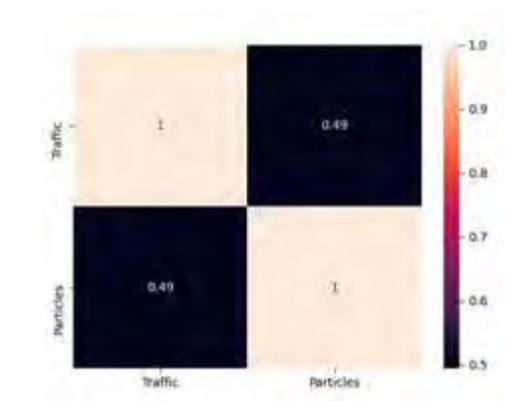


Fig. 7. 2016 New York



*Fig. 8. 2017 New York
An outlier seemingly from the rest of our data showing a very strong correlation.*

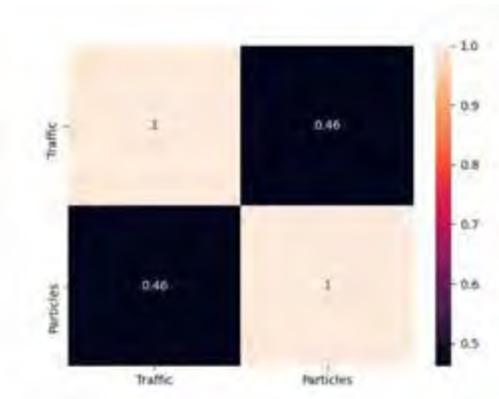


Fig. 9. 2018 New York



*Fig. 10. 2014 Los Angeles
Our weakest correlation, while also being our only one coming out of LA from the limited data*

CONCLUSIONS

Contrary to our original idea, the end result of this paper was a focus on only traffic and pollution as an effective method of measurement and multiple solid pieces of data could not be established to expand it into the area of socio-economic status. We found there is only a moderate correlation between traffic volumes and air pollution, per New York and Los Angeles at least. If we had more years of data we might be able to find a greater correlation or a more telling correlation but as the data is based off of modern API's, so it is lacking in information outside of modern laws and vehicles as its standpoint. As this study focuses on traffic numbers as a whole in relation to pollution, it does not take into account any other method of pollution or method of reducing pollution and could be expanded upon by looking into these other areas.

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INTEGRATING GREEN URBANISM INTO THE TRANSIT-ORIENTED DEVELOPMENT IN AUSTRALIA

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ABSTRACT

Can the combination of green urbanism and transit-orient development (TOD) shrink the environmental footprint associated with vehicular oriented transport? This is just one of the several questions that may be asked when thinking of measures to provide a carbon neutral future. Not only is transport Australia's one of the primary sources of greenhouse gas emissions, but cars alone are accountable for almost half of those emissions. In recent years, the Australian government has made significant investments in the transit systems and the policy agenda has embraced TOD initiatives driven by green concerns. Yet there are some unique challenges in the Australian context. TODs have occurred occasionally in Australian urban development and have not been strategically or statutorily planned. Factors such as rapid transit, density, and mixed use necessary to guarantee the provision of TOD has not yet been put in place in any Australian city. Moreover, while buildings are increasingly consuming more energy in both construction and operation, the execution of green open spaces within and around the TOD is inadequate with the development areas missing on potential environmental benefits and sustainable outcomes. There should be an increased focus on ecological and environmental dimensions of urban development so that the combined effect of pursuing TODs and green urbanism could become a reality in the future.

KEYWORDS

Transit-orient development, green urbanism, vehicular oriented transport, Green TOD, Australia

INTRODUCTION

The environmental footprint associated with vehicular oriented transport has surged significantly following the proliferation of suburban development in the post-war era in both the developed and developing countries [1]. According to Downs [2], one key but undesired feature of an urban sprawl is over-reliance on automobiles for ground movement with people living in the low-density development areas increasingly using private vehicles to access services. By the 1990s, however, many scholars started to question the viability of such a pattern of suburban development as vehicular oriented transport turned out to be one of the main contributors to greenhouse gases (GHG) emission globally. While the search for a sustainable model of urban growth was inevitable, transit-orient development (TOD) emerged as a novel concept to deal with the challenges posed by the sprawl of modern cities.

The term TOD first appeared in 1993 in *The New American Metropolis: Ecology, community, and the American dream* - the book written by a well-known American Architect and Urban Planner Peter Calthorpe. In the book, TOD is presented as a technique to “create more compact, walkable communities” configured around rail transit stations [3], with a focus on the growth-friendly components such as, density, mixed-use and public spaces [4]. According to Cervero and Sullivan [5], over the past three decades, TOD has proved to be a promising tool to break “the vicious cycle of sprawl and car dependence feeding off of each other, replacing it with a virtuous cycle: one where more and more trips shift from cars to transit and compact station-area development slows the spread of sprawl”. This growth model is now viewed favourably as a sustainable approach to urbanism.

However, despite its popularity, there are concerns about adaptability of TOD across all development contexts and its environmental responsiveness. For instance, Yang and Pojani [6] argue that “TOD is not a panacea”, and the model has not always been successfully implemented in cities across the globe [7]. It is also argued that TOD does not adequately respond to the ecological and environmental dimensions of the development pattern [8]. Bajracharya et al. [9] believe that “as a design concept, TOD has evolved as the growth machine risks colliding with ecological limits, necessitating more sustainable planning practices”. While these barriers suggest there is a need for a more adaptive and responsive approach, the need to incorporate green dimensions into the conventional TOD has been strongly recognised in recent decades. Noticeably, urban scholars and practitioners have already started to advocate for integrating green urbanism into the TOD, giving birth to a new concept called “Green TOD”. One of the early and strong proponents of Green TOD, Cervero and Sullivan [5], describe it as an environmentally friendly version of a TOD, in which the combination of TOD with green urbanism can “create synergies that yield environmental benefits beyond the sum of what TOD and green urbanism offer individually”.

It is not surprising, however, to note that Green TOD has not received much attention in the Australian context in both research and practice. It is possibly so because TOD in Australia is limited in practice in the urban development process and has often been adopted as a fad [9,10] rather than a comprehensive strategy to cope with the sprawl. As a consequence, evidence suggests that Australian cities have been less successful in reaping the benefits of the TOD until now. But this realisation leaves us with some important questions. How can the barriers to wider implementation of TOD in Australia be eliminated to better achieve its goals? Does the answer lie in the marriage of green urbanism with TOD? In recent years, the Australian government has made significant investments in the transit systems in place and the policy agenda has embraced TOD initiatives driven by green concerns. Yet there are some unique and emerging challenges in the implementation of the Green TOD. This paper explores such challenges by reviewing the TOD policy measures and the prospect of Green TOD in Australia. It examines how green urbanism may be integrated into TOD and how Green TOD may help in achieving the current goals of sustainable urbanism in the Australian cities.

This paper is organised into four sections. Following this introduction, the next section reviews literature to better understand the concept of green urbanism and its environmental benefits. The third section examines TOD in Australia and engages in the case study of the integration of green urbanism into the TOD in Melbourne by examining the development nodes centred around the rail transit stations in two locations namely, Brunswick and Footscray. The final section concludes the paper by discussing the findings of the case study and offering some insights into the potential measures of integrating green urbanism into TOD in Australia.

UNDERSTANDING GREEN URBANISM AND ITS CONTRIBUTION TO TOD

Green urbanism is a growing topic of interest both in urban research and practice. In the simplest term, it is about bringing nature and/or natural lifestyle into the city. But more than that it challenges our current understanding of urban planning and design discipline and recommends considering issues that would have a direct impact on resilience and sustainability such as, green buildings, water sensitive urban design, sustainable transport, walkable cities, high-density and in-fill development, liveability and healthy communities. According to Newman [11], green urbanism refers to the “settlements that are smart, secure and sustainable”. Lehman [12] defines green urbanism as a “conceptual model for zero emissions and zero waste” that contributes to a more energy efficient city with a lighter ecological footprint that is more beneficial to the environment and the people. In fact, green urbanism stresses on re-evaluating our current approaches to urban development by considering energy consumption and prioritising green areas so that this may lead to the development of truly sustainable cities, both environmentally and socially, and to a carbon neutral future [13].

Integration of Green Urbanism into the TOD

The consideration of green urbanism within the TOD strategies were relatively undervalued until the recent past although growing evidence suggests that there are additional benefits. Huang and Wey [8] argue that the underlying focus of green urbanism on reduced energy use and a more sustainable approach to urban design and landscape architecture can substantially shrink the environmental footprint associated with vehicular oriented transport, resulting in reduced GHG emissions. While the promotion of transit usage also promotes a better mix of urban land uses, creating a network of green transit lines ensures that the population has access to high quality and convenient transportation modes by reducing the dependence on private transports [5]. In addition, this strategy would also result in the reduction of parking spaces on site to increase open space and community gardens so that it would encourage the use of the development area for pedestrians or cycling.

Improving walkability is a major incentive of green urbanism. While much of the development area could be taken up by roads, green urbanism ensures that enough open spaces can be provided to build high quality pedestrian pathways, with the addition of urban landscaping and outdoor seating areas in an effort to encourage public use and activity [14] that are inviting, visually stimulating and well-lit at night [9]. At the same time, the inclusion of continuous segregated cycling lanes would encourage accessibility to public spaces, creating a network of pedestrian and cycling paths to improve the connectivity between locations and access to goods and services. The execution of urban green open spaces within or around TOD aides in the economic value and the sociability of the area, and promotes environmental benefits within the same framework that encourages pedestrian and cycling for a better and more efficient environment.

Environmental benefits of Green TOD

With a growing focus on the significance of green urbanism in examining the role of TOD and its wider impacts on the quality of the built environment, Green TODs have emerged as a combined effort with additional environmental and other benefits. According to Niu et al. [15], Green TOD is “an evolution of the TOD theory, influenced by sustainable development and green urbanism” and “expands the environmental and ecological dimensions of conventional TOD”. The carbon footprints of Green TOD can be 35% less than those of conventional developments, by significantly improving walkability and carbon neutral mobility [5]. This has become possible because:

Green TOD emphasises the coordinated development of transportation, society, and the environment, to build a sustainable and liveable transit-oriented community. Conventional TOD injected new thinking at the social and environmental dimensions by integrating green urbanism and ideas associated with an ecological community [15].

Cervero and Sullivan [5] make a similar observation on the environmental benefits of the Green TODs:

Green TOD offers a form of urbanism and mobility that could confer appreciable environmental benefits. It emphasises pedestrian, cycling and transit infrastructure over automobility. It mixes land uses, which not only brings destinations closer but also creates an active, vibrant street life. And through building designs and resource management systems, it embraces minimal waste, low emissions, and to the degree possible, energy self-sufficiency (p. 216).

They suggest that the benefits of combining TOD with green urbanism can deliver “energy self-sufficiency, zero-waste living and sustainable mobility” and may be realised in terms of: a) higher densities; b) mixed land uses; c) reduced surface parking and impervious surfaces; and d) solar energy production at stations (Table 1).

Table I: Environmental benefits of Green TOD

| TOD | Green urbanism |
|---|--|
| Mobile sources | Stationary sources |
| Transit design: world-class transit (trunk and distribution); station as hub; transit spine | Energy self-sufficient: Renewably powered – solar, wind, organic waste converted to biogas; energy efficiency; district heating/ cooling; combined heat and power |
| Non-motorised access: bike paths; pedestrian ways; bike-sharing/carsharing | Zero waste: recycling and reuse; methane digesters; rainwater collection for irrigation and grey water use; bioswales |
| Minimal parking: reduced land consumption; building massing and impervious surfaces | Community gardens and open space: composting; tree canopies; water-table recharging |
| Compact development mix of uses | Buildings: green roofs; orientation (optimal temperatures); insulation; glazing; air-tight construction; low-impact and recycled materials |

From Cervero and Sullivan (2011)

TOD AND GREEN URBANISM IN THE AUSTRALIAN CONTEXT

Australia has one of the highest per capita carbon footprints in the world. In 2018, Australia’s GHG emissions were 15.5 metric tons per capita as compared with 5.5 in the UK and 8.6 in Germany [16]. Some reasons for this include large dispersed cities, energy inefficient buildings, a reliance on fossil fuels for most energy, high volumes of fossil fuel exports and emissions from agriculture. Transport makes up 19% of total Australian emissions and half of that or around 9.5% is estimated to be due to the private car usage alone (figure 1) [17].

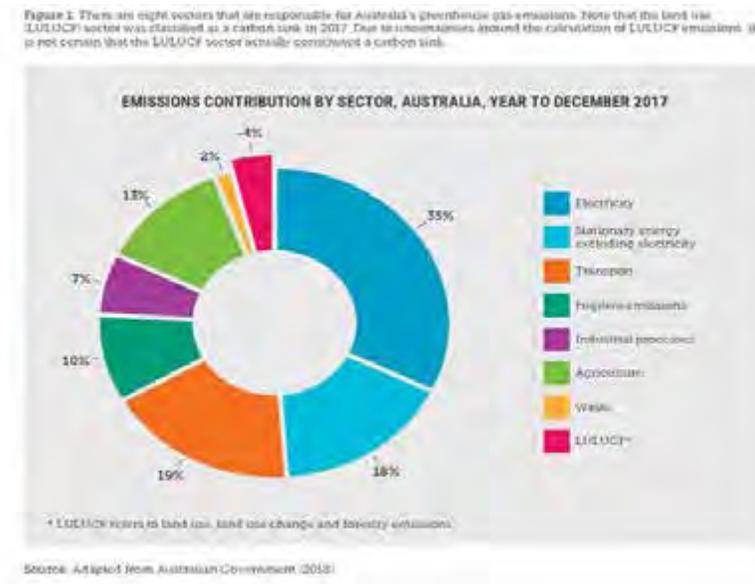


Figure 1. Contribution to GHG emissions in Australia by sector (Source: Climate Council, 2017)

Buildings contribute to a significant amount of GHG emissions too in Australia [18]. Large house size, poor passive solar design and poor insulation coupled with a coal-based electricity supply, the common usage of gas for heating and the now ubiquitous air conditioner all contribute to this. It is worth noting that Melbourne's primary source of electricity is the brown coal of the La Trobe Valley, 140 km to the east, which is burned in huge, inefficient and highly polluting power stations fast approaching the end of their serviceable lives.

Green TOD can assist in improving urban sustainability outcomes in several ways - through reduction in car usage and through more energy efficient building design. At least in theory, flats and apartments should be more sustainable than standalone houses as they are generally smaller, and therefore, consume less resources to build and service. Further, apartment developments generally have a lower ratio of external walls in proportion to floor area than a standalone house as each apartment in large part abuts the adjacent unit, and thus become self-insulating to some degree. In practice, however, while a reduction in car usage is likely in TOD, other sustainability goals have been more elusive. For instance, most residential construction in Australia is privately developed for profit, whereas there has been little investment in public and social housing for decades (although this is now changing). There is also a tendency for many developers to 'max out' the site and to building as tall as possible in order to maximise returns to investors. In the context of Green TOD, this tends to produce high and medium rise buildings with a high embodied energy (the primary materials being concrete, steel, aluminium and glass), which require energy hungry elevators, air conditioning and heating operate. The favoured façade is the (single glazed) curtain wall, and appropriate shading and passive solar design are uncommon. Tall buildings also overshadow the streets, and can create wind tunnels, making them uninviting in winter. Although by 2018, more than 2 million domestic roof top solar PV systems had been installed on Australian houses [19], the uptake of solar in the multi-residential market, such as found in green buildings, has been much slower.

Being profit driven, developers are often reluctant to contribute to the greater common good beyond the confines of their own development sites. In a 2014 study of development in one part of the Melbourne CBD (arguably, a TOD in itself, although a very large one), Hodyl [20] documents how Melbourne developers were allowed to more intensively develop sites, with much higher plot ratios and far less give back to the community, than in five 'high density' global cities including Hong Kong, New York, Vancouver, Seoul and Tokyo. This means that state and local government must provide amenities such as community facilities (schools, child care, etc.) as well as parks and 'green infrastructure'. The environmental credentials of Green TOD developed along these lines may, therefore, be questioned.

THE MELBOURNE CASE STUDY

A metropolis of more than five million people, Melbourne has been experiencing rapid development over the past 30 years. In the past decade (until COVID and associated border closures) an average of 180,000 people moved to Melbourne per year, either from interstate or from other countries, with a rate of 3.69% annual increase in 2020. Despite a boom in high rise apartment towers in the inner city, the bulk of new residents have been accommodated in new, low-density suburbs on the urban fringe, much of which have been built on the fertile farmlands of the western plains or pushing into the bush land of the east and north (figure 2).



Figure 2. Tract Housing, Truganina, 17 km west of the Melbourne CBD

Melbourne consists of a relatively dense 19th century core surrounded by successive rings of low-density automobile dependent suburbs, stretching more than 50 km from the centre. With the exception of the City Loop, the suburban railway system is entirely radial - all suburban lines radiate from the Central Business District (CBD), out to a distance of 40 km from the city centre. Melbourne’s famous tram system is based on the 19th century cable car network, which is largely confined to the inner rings of suburbs built before World War II. While there have been many additional rings added since then, the tram network extends no more than 15 km from the city centre, covering one tenth of the metropolitan area.

TODs have been a central feature of Melbourne metropolitan planning since the release of the Melbourne 2030 report in 2002 [21]. In the report, there is a plan for metropolitan Melbourne along with its various revisions and updates (e.g. Melbourne @ 5 Million, 2008) that have been issued since then and are generally referred to as ‘Plan Melbourne’, six Central Activity Districts (CADs) were identified as sites for TOD - the aim being to transform Melbourne into a polycentric metropolis. The current version of Plan Melbourne formulated in 2017 refers to Metropolitan Activity Centre (MAC), and identifies several more ‘MACs’ than in the 2008 version, as well as some future MACs (figure 3) [22]. All MACs lie on major rail lines, and connect to various other modes of transport such as, bus, tram, cycle paths, pedestrian networks, and the private car. All the CADs identified for development and intensification utilise existing suburban nodes as their ‘seed stock’. Strangely, only two of the six CADs will be connected into the proposed Suburban Rail Loop as part of the plan to turn Melbourne’s radial suburban railway into an interconnected network. The nine MACs are augmented by a hierarchy of numerous smaller ‘major activity centres’, both of which have the potential to incorporate some elements of TOD and green urbanism.

Plan Melbourne has formalised a process already well underway as most MACs were pre-existing suburban centres and several of which had histories as independent towns before they were swallowed up by the relentless expansion of the suburbs. By identifying the MACs as sites for high density development, the state government may simply have given the ‘green light’ to yet more speculative developers, without necessarily maximising community and environmental outcomes. In the next sections, we examine the prospect of green urbanism and its potential integration into the TOD in Brunswick and Footscray.



Figure 3. Metropolitan Activity Centres (Source: Plan Melbourne, 2017)

The Brunswick Spine

Brunswick is a rapidly gentrifying ‘hip’ inner suburb located 4 km north of the Melbourne CBD. From the early 20th Century, Brunswick was an industrial suburb, providing employment for a large working-class population, which in the post war era became increasingly migrant dominant largely drawn from southern Europe and the middle-east. Linear shopping strips serviced by the trams are a characteristic of Brunswick. The Sydney Road shopping strip, at 4.5 km in length with the trams running north - south, is the longest in Melbourne and is a classic example of this kind of 19th century transport-based urbanism. Running roughly parallel to Sydney Road is the Upfield Railway line. The distance between the two varies from 200 to 250 m. The land between Sydney Road and the railway line forms a ‘spine’ of mostly former industrial land, mixed with other uses that runs from Brunswick Road in the south to Moreland Road in the north at a distance of around 2.4 km (figure 6). There are three railway stations, Jewell, Brunswick and Anstey in the Spine, as well as the recently redeveloped Moreland Station just north of the area. Alongside the railway line is a bicycle path, which connects with the University of Melbourne and medical precinct and the Melbourne CBD to the south and to Coburg to the north. Six bus lines cut across the Spine in an east-west direction. Nowhere in the Spine is more than 100 m from either the railway, bike path, bus or tram.

The Spine represents a TOD precinct and evidence shows some promising signs of green urbanism and sustainable development and it may set an example to be emulated elsewhere in Australia. Over the past decades, the industrial sites in the Brunswick Spine have been increasingly redeveloped for residential use. The dominant mode of development has been medium rise buildings of 5 to 10 storeys in height, with architectural and sustainability outcomes of mixed quality. While all new residential developments must meet minimum environmental standards, most do no more. Some apartment blocks have PV solar panels on the roof, but often orientation of windows is determined more by site constraints and maximising yield than by basic passive solar design principles. Insulation and appliance efficiency is generally what is required by building code and no better.

There are, however, some signs of changes. Starting in 2014 a series of residential apartment blocks have been built in the Spine challenging the prevailing development model. The Commons, an architect-initiated development based on the German *Baugruppen* model, took advantage of a ‘problem site’ adjacent the railway line, which was cheap to buy because of perceived noise issues, and where a lack of neighbours allowed a greater volume than might be allowed elsewhere in the Spine (figure 7). This type development model is new to Australia, but the Commons also broke new ground in regards to sustainability. Arguing proximity to multiple forms of public transport and the bike path, the Commons was exempt from standard car parking requirements. The building achieves a 7.5-star rating for energy efficiency (2.5 stars higher than required), uses low toxicity materials (for example, chrome was forbidden), and boasts communal vegetable garden, BBQ and laundry and as well as solar panels on the roof. Car ownership is forbidden. Instead of underground car parks, there is ample on-site bike parking and two share car spots in the street. Because of its not-for-profit approach to development, a refusal to engage with estate agents, publicists and marketing, and the elimination of underground car parking (at \$40,000 per space according to Breathe founder Jeremy McLeod), the Commons was able to deliver highly sustainable, compact, community-oriented housing at market competitive prices.



Figure 6: Brunswick Spine: adapted from Brunswick Structure Plan (Source: City of Moreland, 2020)

A second development based on the Commons, the ‘Nightingale’, was built immediately across the road a few years later. The success of the Commons and the Nightingale were used to launch the Nightingale model of housing development. Four projects have now been completed, twelve more in construction, and more are in preparation. Many of these are being built near the Commons and the original Nightingale in the Brunswick Spine, at the new Nightingale Village. Each project is designed by a different architect and many of the leading lights of Melbourne architectural community are now involved in Nightingale projects. As with earlier Nightingale projects the buildings in the new Village will include the high levels of sustainability - all are certified carbon neutral and powered by Green Power, use passive solar design and cross ventilation (figure 8).

The original plans for the Nightingale Village included provision of a future park, which has now been built. The construction of Bulleke-Bek Park in the village demonstrates, in miniature, a vision for future sustainable development, combining the benefits of TOD with sustainable, high density development and green urbanism (figure 9). Developed by Moreland City Council, over several years of community consultation, Bulleke-Bek provides much needed green open space in what, in Australian terms, is a high-density urban environment. If this model were to be adopted more widely, both in the Spine and beyond, it would help improve the urban environment, provide high quality sustainable housing and establish a new benchmark for sustainable urbanism in Australia. Indeed, the Moreland City Council is planning a further five new parks, including three in or near the Spine [23].

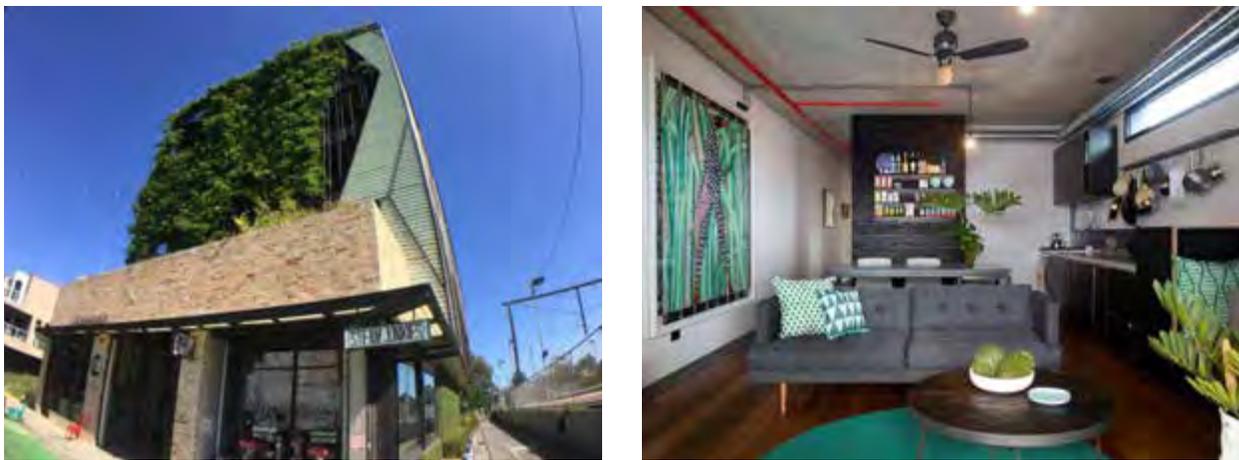


Figure 7. The Commons, Florence Street Brunswick (Source: Breathe Architects, 2014)



Figure 8. The Nightingale Village in the Brunswick Spine (Source: Nightingale Housing, 2021)



Figure 9. Bulleke-Bek Park in Brunswick

Footscray

Footscray is a working-class inner suburb located 5.5 km west of the Melbourne CBD. It is bordered to the north and east by the Maribyrnong River. Footscray was a formerly a manufacturing centre, but has largely deindustrialised and is gentrifying. It has a highly diverse population, and high levels unemployment and disadvantages. Footscray station has been recently redeveloped and is a major focal point in the rail network, servicing three suburban rail lines as well as regional lines to Geelong, Bendigo, Ballarat and Warrnambool. The station connects to multiple suburban bus lines, as well as the Moonee Ponds tram line and the urban bicycle network.



Figure 10. Central Footscray Structure Plan showing proposed heights (Source: Maribyrnong City Council, 2014)

Footscray was identified as a TOD in Melbourne 2030 [21] and development has been proceeding rapidly over the past decades. Central Footscray is slated for redevelopment, with building heights from six to ten storeys proposed, some of which are already built [24]. Three precincts are set aside for more intensive development. The South Precinct, a short walk from of Footscray Station, has already been developed with the 14 storey State Trustees Building, which is a glass box (figure 10). There is a small park, and a Railway Reserve to the north of the building between it and the station. Although Footscray Station itself has recently been redeveloped, the Station Precinct is yet to see much new residential or commercial development. There is a bus interchange and small plaza in front of the station and the Moonee Ponds tram terminates there. There is limited open space in the area. Maddern Square, a small urban park is several few blocks away as is the Nicholson Street Mall. There are no plans for new open spaces in the Station Precinct [25].

The largest scale development in Footscray has been on the Riverfront Precinct along Maribyrnong River - an area identified by the Footscray Structure Plan as available for 'maximum change', with height controls allowing for developments up to 14 stories [24]. However, several of the newly built apartment towers exceed 20 floors in height (figure 11). The Riverfront Precinct is located around 800 m north east of the station, on Hopkins Street, one of the main roads to the City. Extensive development in the past five years has resulted in a large concentration of tall buildings at the 'gateway' to Footscray. The buildings are mostly curtain wall towers, built boundary to boundary. There is almost no attempt at appropriate orientation, sun-shading or basic sustainable design measures. In some cases, glazed walls are oriented to the west, maximising solar heat gain in summer. Solar panels are rare. The Riverfront Precinct takes advantage of the existing parkland along the river front, and has views of the river and the city. No new parkland is planned [25] although two small 'potential plazas' are suggested for the precinct in the Footscray Structure Plan [24]. The precinct is still being developed, but it is evident from the completed buildings that the back streets of the Riverfront Precinct will be largely overshadowed, windswept and visually dominated by the bulk of the closely spaced towers.



Figure 11. Footscray development along the Maribyrnong River

DISCUSSION AND CONCLUSION

Findings from the two suburbs in Melbourne suggest a mixed outcome in terms of their potential for integrating green urbanism into the TOD. In general, it appears that the inner suburbs are doing much better in their performance as a TOD as compared to the newly developed outer suburbs. But when it comes to the features of green urbanism and its integration into the overall urban development pattern, there is a clear lack of policy measures and development guidelines in all areas. In turn, the 'integration' of green urbanism has been left up to the individual developers and their overall tendency towards achieving environmentally sustainable outcomes in site planning and building design. Green open spaces are usually a priority in urban development in Australia as evident in the both cases, but their success is determined by proximity to the residential areas and integration with other services and urban amenities. These outcomes highlight the need for more sustainable urban planning principles in the future. We will now discuss the findings by briefly assessing the three main aspects of a Green TOD: a) urban layout and proximity to the services; b) green open spaces; and c) architectural design response.

Urban layout and proximity to the services

The Brunswick Spine suggests that inner city areas respond better to a TOD and performs well to achieve excellent urban design with their compact and walkable neighbourhoods. There is no or very little need to use vehicular oriented transport to access services. The urban layout also shows evidence of infill development with the conversion of industrial buildings into residential ones. This needs to be encouraged as it helps in achieving higher residential density. In contrast, although identified as a potential TOD, Footscray development suggests that Melbourne's outer suburbs are less compact in layout and represent the development of an urban sprawl, which are highly car dependent and do not promote walkability. Yet, the development of the tall apartment buildings as seen in Footscray may help achieve medium residential density.

Green open spaces

Brunswick area shows some traces of existing green open spaces along with the development of the new parks through the initiatives of the local city council. Although there are areas of parkland outside of the area to the south and west, there is a lack of green open space in the Spine suggesting that more is needed. The case is little different in Footscray, where the existing green open spaces could perform better by adding a strong network of green corridors and establishing a better connection within the suburb.

Architectural design response

Green buildings are emerging in Brunswick as evident in the newly built housing complexes such as, the Commons and the Nightingale, which indicates a new impetus in achieving green urbanism in an existing TOD friendly urban area. The architectural design response, despite the existing site constraints, has been highly favourable towards achieving energy efficient and sustainable building outcomes – the buildings performs well in energy rating. There is, however, little response to the green dimension of building design in the case of Footscray, where, as evident in the building façade, most curtain wall residential towers are less energy efficient, with a rare use of solar panels in them. In part, this is due to the fact that the prevailing residential development model is profit driven and built by private developers, with a tendency to maximise individual profit over green concerns and public benefits. This suggests that green buildings are not easy to realise and will only be successful if state and local government act to deliver public policy measures and planning guidelines to ensure the wider public benefit by providing the green infrastructure, public services and amenities and energy responsive building design outcomes.

The Brunswick Spine presents exciting possibilities as a linear TOD. It has excellent public transport links at a variety of scales. The Spine is highly walkable, the topography is gentle, with a slight uphill slope to the north. Nowhere is far from the activity of Sydney Road. On the other hand, the Footscray TOD may offer potential for green urbanism, but to date has underperformed. Steps need to be taken to improve the environmental performance of the buildings, and to create more quality green open spaces. To date, maximising profit - and views - has clearly taken precedence over sustainability and community in the design of the buildings and the urban environment of the Riverfront Precinct.

Although the practice of TOD has been somewhat limited in Australia, it has now returned to the government policy agenda with is a growing consensus on its apparent benefits among stakeholders. Recently, the Australian government has made significant investments in the transit systems in place and the policy agenda has embraced TOD initiatives driven by green concerns. Yet there are some unique challenges in the implementation of the Green TOD. Firstly, TODs need to be strategically and statutorily integrated in urban planning and development regimes. Secondly, this needs to be supported by execution of the integral factors of a successful TOD such as, rapid transit, density, and mixed land use. Thirdly, there has to be adequate and integrated execution of green open spaces within and around the TOD. Once such challenges are met, it is imperative that further steps are to be taken to move beyond the conventional TOD by engaging in a more adaptive and responsive approach that aim for sustainable urban development. In other words, there should be an increased focus on ecological and environmental dimensions of urban development so that the combined effect of pursuing TODs and green urbanism could become a reality in the future.

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CLIMATE SENSITIVE URBAN REGENERATION: EXPERIMENTING AN ADAPTIVE AND ZERO-ENERGY APPROACH IN TRENTO, ITALY

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ABSTRACT

Mitigation and adaptation to the implications of climate change are currently main issues to be tackled in transforming the existing built environment. Design practices mostly focus on energy retrofitting, limiting the integration of environmental criteria of outdoor spaces and considerations of future scenarios. A good integration between mitigation and adaptation strategies is foreseen to effectively balance urban health, environmental quality and energy performances through an integrated approach.

According to several studies, integrated and multiscale approaches to regenerate the built environment represent an effective asset for the urban fabric, improving the urban quality and delivering simultaneously several functions. The main aim of the study is the definition of tools for practitioners to tackle climate-related challenges with an integrated approach. A performance-based approach is outlined to combine microclimate regulation, runoff mitigation, energy consumptions and urban quality. The proposed workflow is divided into general criteria, which define priorities and potentialities of intervention in the study area, and feasibility criteria, to decide which solutions to choose according to technical, regulatory and landscape integration aspects.

The study is carried out in Trento, an Alpine city in the North of Italy, developed along the river Adige. Despite the rich natural landscape of the hillsides, the valley is strongly urbanized, with soil sealing leading to urban heat island effect and stormwater management challenges. The paper provides design solutions to promote low energy, adaptive and healthy urban regeneration interventions at the neighbourhood level, focusing on the transformation of urban surfaces and their physical characteristics.

KEYWORDS

urban regeneration, adaptive approach, zero-energy neighbourhoods, multifunctional surfaces

INTRODUCTION

Urbanization and growth of urban population have been increasing at an unprecedented rate: half of the population is living in cities, and it is expected that by 2050 it will reach up to 68% [1]. Cities have a key role in facing the challenges related to climate change: on one side they are responsible for 60-80% of energy consumptions and for around 75% of greenhouse emissions, being within the major contributions to climate change; on the other side, they are very vulnerable to the impacts of climate change, causing risks for infrastructures, services and people [2].

The United Nations (UN) and European Commission (EC) recognized the role of cities by targeting them respectively in one of the 17 Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development [3], and in the Pact of Amsterdam, defining the European Urban Agenda [4]. Hence, cities constitute hubs of intervention and can contribute to tackling several challenges.

In this framework, climate adaptation and mitigation represent urgent issues requiring profound transformation of urban metabolism and regeneration of the built environment. The reduction of emissions can be in synergy with the creation of robust and healthy cities, by creating a good balance between mitigation and adaptation strategies [2].

Climate-related challenges in cities have been widely addressed by European efforts and policies. However, their implementation by means of effective practices and transformations is still slow. Moreover, the implementation of adaptation and mitigation strategies is often treated separately, due to, for example, their separation in the European policies, their different spatial and temporal scale of intervention, and lack of legislation [e.g. 5,6].

However, cities represent an intermediate scale connecting the strategic policies with their implementations and, by being the place where the transformations occur, they should promote urban transformations that tackle simultaneously several challenges, by connecting the local with the global policies. Moreover, urban planning tools can include adaptation requirements according to the vulnerability to the impacts of climate change of areas, to orientate design processes towards an increase of the adaptive capacity.

The paper draws upon the idea of enhancing the integration between adaptation and mitigation strategies through climate sensitive design practices. It reports the preliminary results of a study aiming to propose an integrated approach for urban practices, effectively balancing urban health, environmental quality and energy performances. Specifically, it investigates the physical characteristics of the built environment influencing the climate related challenges and their interrelations, and it defines an analytical framework for design practices to prioritize solutions achieving multiple functions, by means of a case study.

The case study is developed within Trento Urban Transformations, a research project carried on by the Department of Civil, Environmental and Mechanical Engineering (DICAM) at the University of Trento aiming to propose innovative and adaptive urban planning tools. The paper constitutes the first stage of an experimentation of the performance-based approach developed in the research project, focusing on the climate and energy challenges.

CLIMATE-RELATED CHALLENGES

In the current scenario of urbanization and climate change, cities need to move towards better quality of urban life, safety in case of extreme events, and sustainability. Urban transformations should not prioritize climate change mitigation (i.e. reducing greenhouse emissions), but should also focus on the capacity to recover and on the creation of a healthy baseline, to facilitate more liveable cities for people (i.e. adaptation) [2]. Thus, implementing a regenerative approach for urban transformations could constitute a good asset for this issue, and improve the relationship between humans and the built environment, by creating a framework that considers building energy performances, environmental impacts, resilience to climate change and human needs [7].

According to the framework of the Trento Urban Transformations research project [25], the proposed method is based on challenges rather than objectives, allowing flexibility and continuous development of strategies and tactics [8].

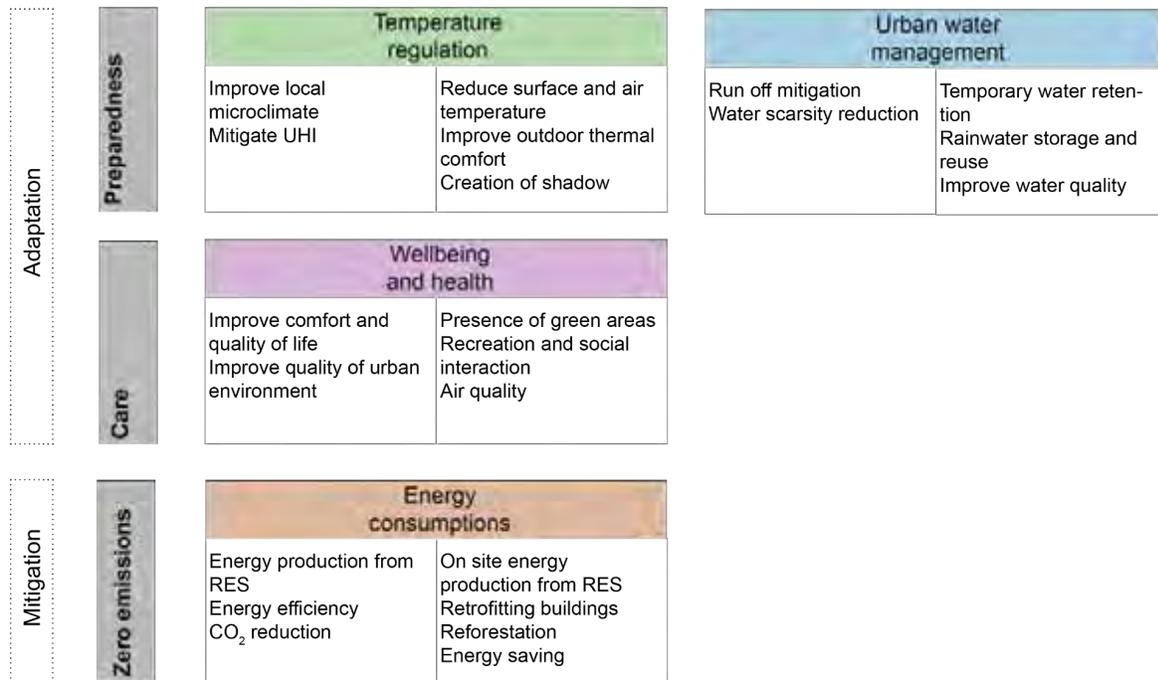


Figure 1. Climate-related design framework: definition of specific objectives and required performances for each climate and energy criteria

To set a clear framework to pursue urban, environmental and ecological quality improvement, four main climate-related challenges have been defined: temperature regulation, sustainable water management, inhabitant’s health and wellbeing and energy sustainability. For each challenge, specific objectives and required performances have been defined, to provide strategies and tools to be applied in the built environment (Fig.1). The specific objectives represent actions that can be implemented by urban transformations, defining a design-framework; while, the performances constitute a driver to the implementation of the specific challenges, by indicating possible tools and quantifiable criteria, understandable by practitioners. The definition of the performances relies on the relationship between the built environment and the urban climate, and depends on the parameters of their interactions.

Temperature regulation

The relationship between urban climate and humans is complex. Urbanization, and specifically densification, led to the phenomenon of Urban Heat Islands (UHI), which consists of higher temperatures in the urban areas compared to the surrounding rural ones. Its main causes rely on morphological and physical characteristics of the built environment, as well as anthropogenic factors such as traffic and cooling systems. Moreover, UHI is exacerbated by global warming and heat waves, being a risk for health and comfort of people [9]. Therefore, to address temperature regulation in design practices, the focus should be both on reducing the UHI effect and improving local microclimate conditions.

Sustainable Water Management

Integrated water quality and quantity management is becoming an important issue in recent years. Urbanization and uncontrolled growth of soil sealing created an increase of water demand as well as difficulties to manage stormwater. Hence, the traditional management of water, based on directing runoff to waterways through the sewer system, has shown difficulties to respond to recent phenomena. In the last years, European and national policies have been promoting rainwater management in a diffuse way and considering water as a resource, based on a localized and diffuse lamination, natural depuration, water reuse and infiltration in the soil. This approach contributes to maintaining hydrological balance as well as improves biodiversity in the urban environment.

Being based on the maintenance of hydraulic invariance, sustainable water management can be pursued through land use transformation, by integrating vegetation and pervious surfaces capable of infiltrating, retaining and purifying runoff [10].

Energy sustainability

Regenerating the built environment constitutes a key action to limit greenhouse emissions and to contribute to climate change mitigation. The three main actions promoted by European policies in the built environment are: production of local energy from RESs, retrofitting the built environment to improve energy performances, and reducing emissions by energy saving [11]. Often the optimization of energy demand is developed for the single building and does not consider the interactions of the surroundings with the urban environment, limiting the efficiency of the solutions.

Health and wellbeing

Urban regeneration aims to improve social quality of life, livability and health, by making urban spaces more attractive [12]. Design practices, at any scale, should promote sociality, integration and inclusion as well as wellbeing, health and accessibility. In general, the aim is to promote actions ensuring safe and comfortable conditions, both from a physical and psychological point of view, and the sense of belonging.

ROLE OF THE BUILT ENVIRONMENT

The pursuit of the above-mentioned challenges and specific objectives, such as temperature regulation and sustainable water management, involves actions at various scales of intervention, different disciplines, and actions in both public and private spaces. In a multi-scalar framework, therefore, the actions implemented by single practices constitute a possibility to contribute to the challenges and to regenerate the urban fabric through small interventions. The regeneration of buildings and larger areas with climate sensitive solutions contributes to the micro scale as well as to urban quality, if they create a network of connected urban spaces.

Thus, transforming urban components, such as building envelopes, parking lots, streets, by using solutions such as Sustainable Drainage Systems or Nature-based Solutions contribute to urban, environmental and ecological quality.

To simultaneously achieve mitigation, adaptation and wellbeing, the transformation of the built environment should aim at achieving the performances defined in the previous paragraph, by intervening on the parameters of the built environment which interact with the urban climate.

The present paragraph focuses on the relationship between urban climate and the built environment, and reviews the mechanisms and parameters involved. This step allows the definition of the performances that the built environment should improve to tackle the climate-related challenges, by means of design requirements.

Specifically, according to literature studies, four systems of the built environment can be identified for climate sensitive urban transformations: urban geometry, vegetation, water bodies and surfaces. The parameters of the built environment interacting with the urban climate have been investigated, focusing mainly on the urban thermal environment. The physical parameters most used to describe the urban thermal environment [13] are air temperature, thermal radiation, wind speed and humidity.

The above-mentioned parameters are independent from each other, but can be integrated into equivalent temperature, to evaluate the outdoor thermal comfort.

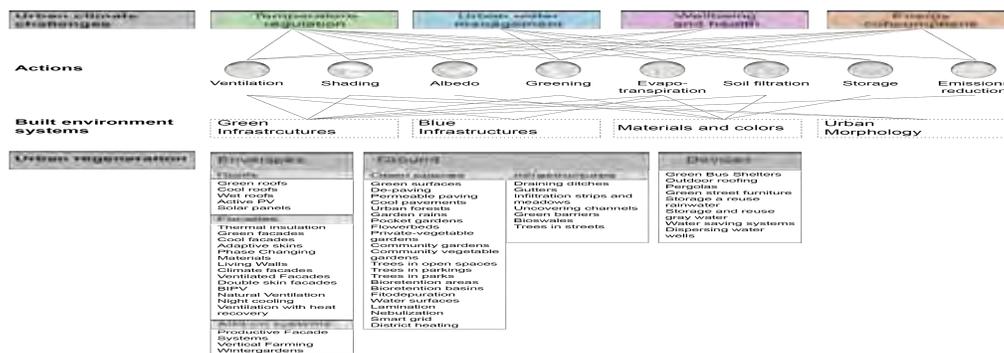


Figure 2. Interrelation between climate-related challenges and the systems of the built environment

To sum up, a simplification of the interactions is reported to understand their implication on the climate-related challenges [13]. Such interactions constitute the base for the definition of the performances of climate sensitive urban transformations and the identification of parameters for their evaluation. Urban geometry changes radiative and convective heat transfer: compact outdoor spaces block solar radiation through shading, but reduce wind. Streets with orientation parallel to wind direction improve comfort by improving ventilation. Vegetation has several benefits: it reduces short-wave radiation by shading and long-wave radiation, reducing surface temperature. Moreover, it increases the permeability of the spaces, improving soil filtration. The surfaces influence the solar absorption affecting the surface temperature and the capacity to filtrate or storage water. Water bodies, by means of evaporation, reduce air temperature of outdoor spaces and improve ventilation in urban spaces, according to the wind direction.

Considering the parameters of the built environment interacting with the urban climate, as well as the factors that influence sustainable water management, energy consumptions and health and wellbeing, the characteristics of the built environment that play a role in climate sensitive design have been collected. Such characteristics can belong to different systems of the built environment and can influence simultaneously more climate-related challenges, as highlighted in Fig.2.

Based on the studies reviewed [e.g. 13,14,15,16], the characteristics of the built environment interacting with climate, which can drive the choice of the design solutions, are ventilation, shading, albedo, greening, evapotranspiration, soil filtration, water storage and emissions reduction. Particularly, temperature regulation can be tackled by intervening on ventilation, shading, albedo, use of greening and evapotranspiration. Changing such characteristics can reduce surface and air temperature, improve outdoor thermal comfort and block solar radiation, thus reducing the UHI effect and improving local microclimate. Sustainable water management can be achieved by the use of greenery, water storage and soil filtration, which allow temporary water retention, storage and reuse of rainwater and improvement of water quality. Energy sustainability can be pursued by working on emission reduction, use of green and indirectly on ventilation, shading, evapotranspiration and albedo, since they reduce the need to use cooling systems. Health and wellbeing of the inhabitants can be obtained with actions on greening and on shading, which contribute to create green and social areas as well as to improve air quality.

The effectiveness of solutions on the climate-related challenges is different and depends on several factors, such as the location, the type of soil, and urban compactness [13,14]. For this reason, the choice of the specific solutions depends on the area of study.

PROPOSED INTEGRATED APPROACH FOR URBAN REGENERATION

The proposed approach (Fig. 3) aims to define an analytical framework systematized in steps and defined by specific criteria, to guide the transformation of the urban environment through an integrated approach.

It is divided in two main parts: the first one defines a wide range of possible climate-proof solutions for the area; the second one selects the most feasible solutions, according to technical, regulatory and landscape integration parameters.

The first step of the integrated climate-proof approach is the characterization of the area: it investigates the environmental characteristics (i.e. understanding the current situation of climate-related performances), defines the urban geometry (i.e. assessment of urban systems: blue and green infrastructure, morphology and surfaces) and the urban quality to identify systems or spaces that require regeneration. The objective of the first step is to improve the knowledge of the area of intervention and understand the interrelations between climate challenges and the built environment.

The results are used to identify the performances that need to be improved in the area, aiming to regenerate the urban environment to be prepared for future scenarios, to be neutral in terms of emissions and to foster quality and safety in the space. The defined performance targets are prioritized through a multi-criteria analysis process.

The second step is the definition of the possible systems of interventions based on the knowledge acquired about the area. Considering the interrelations between the built system and the urban climate [17], a framework of 7 systems of interventions have been outlined, characterized by different levels of complexity and scales. Starting from a big scale to the integration of devices, the transformations regard (1) the morphology of built form, by addition or removal of volumes, (2) the urban canyon, by changing the ratio between buildings and open spaces, (3) building design, by promoting bioclimatic and passive solutions at the design stage, (4) surfaces of the envelopes as well as of the open spaces, (5) Blue and Green Infrastructure, which should be enhanced considering the multiple functions, (6) energy systems, to improve energy efficiency as well as energy production from renewable sources, (7) water systems, to store and reuse water.

The selection of the type of devices to use is carried out by combining this approach with the study of feasibility of solutions. The feasibility is meant as i) technical, including design parameters and recommendations collected from literature studies [e.g. 18-22]; ii) regulatory, consisting of the identification of performance requirements and specific limitations of the area; iii) related to the landscape integration, so that the proposed solutions are not only efficient but also accepted by the community.

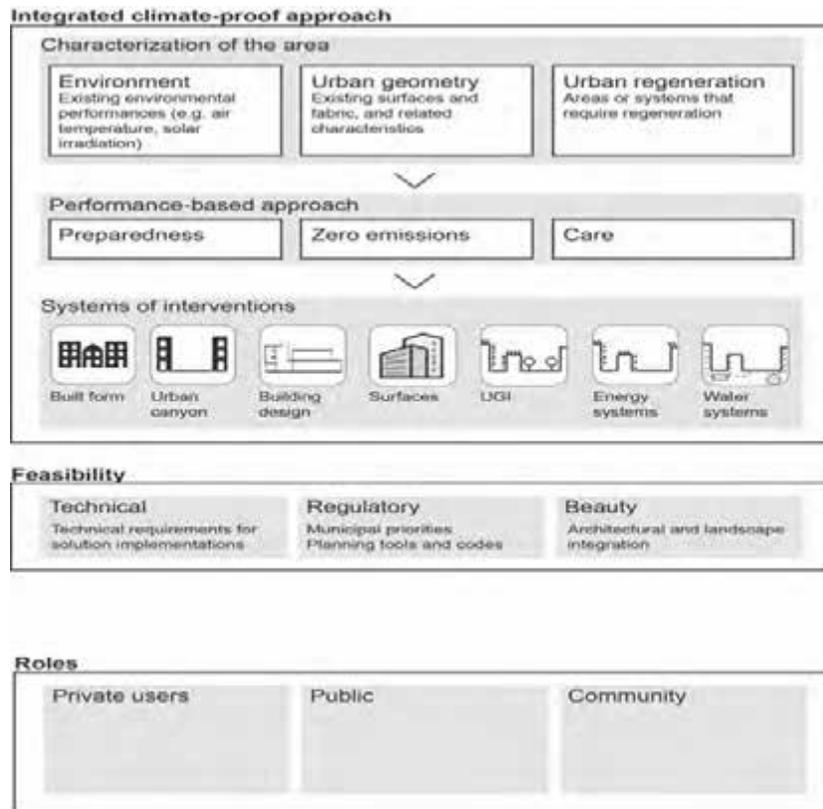


Figure 3. Proposed integrated approach to guide climate sensitive urban regeneration

A RESIDENTIAL AND COMMERCIAL NEIGHBOURHOOD IN TRENTO, ITALY

The proposed approach has been applied to an existing district in Trento, a small city in North-East of Italy along the Adige valley. Despite the rich natural landscape of the hillsides, the valley floor is strongly urbanized, leading to Urban Heat Island effect and stormwater management challenges.

The method is tested in a strongly urbanized neighbourhood located in the northern part of the city. The neighbourhood is characterized by a mix of commercial and residential buildings, mostly large low rise typology, with large surfaces and lack of soil permeability.

At the municipal level, temperature regulation is a priority in the urban core, but there are no specific guidelines on the local strategy to attain it. The updated Energy and Environment Plan of the Province (PEAP) defines strategies such as deep retrofitting and increase of local energy production from renewable energy sources, both in industrial buildings and residential ones [23]. Moreover, the area has a potential hydrological risk, due to soil sealing and the presence of a canal [24]. A lack of public open spaces is detected, which, combined with the presence of large impervious surfaces used as parking lots, reduces the urban quality of the area. Some results from the study on the characterization of the area are shown in Figure 4.

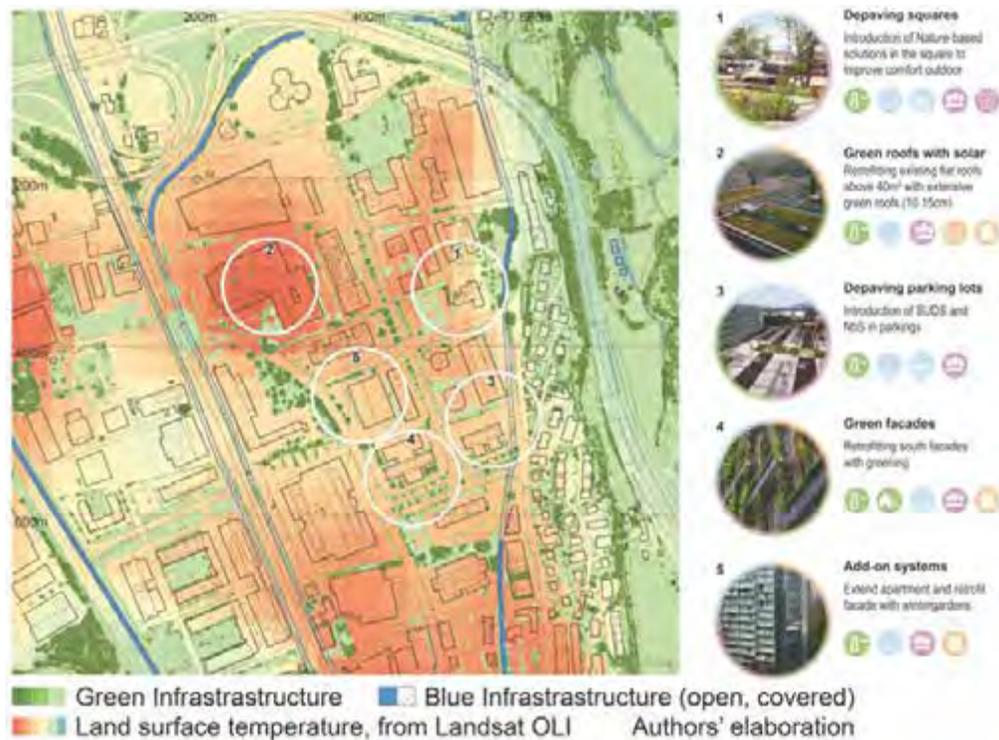


Figure 4. Application of the proposed method in a mixed-use neighbourhood in Trento: map and analysis of the characteristics of the area and proposal of possible types of interventions.

Based on the analysis of the area and on the local priorities defined by the Municipality, the main performances required in the area are: temperature regulation; energy efficiency; energy production from renewable energy sources; increase of green areas to improve community's health and wellbeing.

Considering that it is an existing district and that the focus of the study is to propose regeneration strategies, the system of intervention that can be developed are the transformation of surfaces, the implementation of Blue and Green Infrastructure and the integration of energy and water saving systems.

The great amount of surfaces, both on ground and the flat roofs, constitute an opportunity to regenerate the existing environment, mainly with strategies of depaving and retrofitting, by introducing Nature-based Solutions, Renewable Energy Sources and Sustainable Urban Drainage solutions, which can provide multiple ecosystem services and improve the quality of the area.

According to the framework developed in the Trento Urban Transformation research project, the above mentioned solutions will be implemented in the urban components, mainly focusing on parking lots (which cover around 43% of the district) and flat roofs (which cover around 25% of the district). Moreover, facades of the buildings can be retrofitted, in order to improve the energy performance as well as the quality of the landscape.

The proposed solutions for the parking lots are the integration of SUDSs, such as drain ditches in the borders of the areas, to reduce water runoff, and pervious surfaces and vegetation, to contribute both to temperature regulation and water management.

The roofs of the buildings are mainly flat: a part of them is used as parking lots, and they could be transformed with cool materials, such as cool paintings with values of albedo around 0.8; while some are unused and could be integrated with solar green roofs to combine energy efficiency and onsite renewable energy production, as well as biodiversity preservation and runoff reduction [26].

Facades constitute an opportunity to improve energy performances of the buildings both in summer and winter conditions: vertical greening systems can be integrated on the south exposed surfaces; shading systems should be implemented in the south exposed facades and could be integrated with PV systems to produce energy; add-on systems (i.e. independent wintergarden) in east-facades represent a solution to improve energy efficiency, quality of the space and creation of shaded areas around the buildings.

CONCLUSION

The main purpose of the study is to investigate the key role of the built environment in tackling climate related challenges, to improve resilience, wellbeing and sustainability in cities. The paper reports the preliminary results of a study in the framework of Trento Urban Transformation research project and Horizon 2020 PEARLS research project, focusing on the experimentation of multiscalar approaches (ranging from planning to design practices) and multidisciplinary topics with the aim to propose a method facilitating climate sensitive regeneration in cities through an integrated approach.

Aiming to define an integrated approach, climate related challenges in urban environments have been identified and their interrelations with the built environment have been analysed, in order to understand which parameters of the built environment can be transformed in an efficient way.

Based on this, a framework, meant as a guideline for practitioners, has been proposed and developed through several steps: characterization of the area from an environmental, morphological and qualitative point of view; definition of priorities according to the Municipality strategy and to the characteristics of the area; the identification of systems in which it is possible to intervene; choice of specific devices according to regulatory, technical and landscape integration feasibility.

The methodology has been tested in a mixed-use neighbourhood in Trento, and focused on the definition of regenerative solutions that could provide benefits on climate adaptation and mitigation by improving the quality of the area.

Further developments of the study will include the experimentation on other typologies of districts and a more accurate selection of solutions according to technical criteria. Moreover, the study will be followed by the evaluation of the environmental performances of the solutions, to understand to which extent each solution can contribute to climate adaptation and mitigation in the specific case study.

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AN APPROXIMATE CALCULATION FOR UNDERSTANDING RELATION OF URBAN SPATIAL REGULATION AND “UHI” WITH CASE OF TROPICAL CITIES.

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ABSTRACT

The problem of Urban Heat Island (UHI) in Tropical Cities is generally triggered by a large amount of solar radiation. However, it can also be caused by inappropriate spatial regulations. In general, the code regulate the function of land use and the number of restrictions on values of BCR, GAR as well as FAR. This paper shows a simple calculation method to determine the land surface temperature (LST) of the outdoor material as indicator of UHI. A one-dimensional heat transfer model is applied in this calculation, which simply relies on the use of a spreadsheet. As spatial variables in this calculation simulation were the configuration of the space use, type of surface material and configuration of building. While the climate variables include solar radiation, air temperature and wind. Variation of green open space by applying GAR from 30% to 100%. GAR 100% represents an urban forest, while 30% represents the city center. The calculation also applied variations of the value of BCR (0 to 60%), road space area (0 to 20%), and pavement space ratio (0 to 16%). The maximum LST calculation output were then compared to the results of studies from other researchers that use satellite imaging methods. The results show a moderate difference, it were not exceeding 10%. The case study areas were the cities of Surabaya, Bandung and Semarang in Indonesia. This method of calculation can be used easily to test the reliability of a city spatial regulation in terms of reducing UHI.

KEYWORDS

Urban Heat Island; Land Surface Temperature; Urban Code; Tropical City

INTRODUCTION

In the process of architectural design and urban planning in general always consider the influence of various variables that include climate components and the nature of the skin material or building envelope and the type of ground cover material. Consideration of these variables is intended to obtain an optimal and quality design from the point of view of sustainable development goals and to achieve the thermal comfort of outdoor space areas. On the other hand, the fact that cities in the world have urban planning regulations that include rules about spatial planning, and regarding building configurations. These regulations are formulated and implemented with the aim that sustainable life can also take place in the city. To achieve the goal of success in sustainable development, these regulations need to be taken into consideration. In relation to building configurations, many cities in the world apply regulations on urban space that includes restrictions that apply to any land delineation regarding BCR (Building Coverage Ratio), FAR (Floor Area Ratio), BD (Building Density), GAR (Green Area Ratio), GOS (Green Public Open Space) and even RAR (Road Area Ratio). In addition there are also restrictions regarding the percentage of green open space in the city area. However there are also urban spaces that impose restrictions on the maximum number of floors, as well as the percentage of circulation areas and public transportation. Various variables applied to the regulation will have an impact on the risk of Urban Heat Island (UHI).

The problem is that we sometimes do not know what formulations we can use to calculate the impact of these regulations on UHI. We do know that the denser the urban area, the warmer the area causes an increase of UHI. However, we sometimes cannot quickly predict or calculate the heat flow and radiation temperature in the downtown area due to the application of urban spatial regulations. Several researchers have simulated the effect of building configuration on microclimate using commercial software such as Envi-met ([1], [4], [12], [13], [14], [17], [43]) or even use other CFD codes like ANSYS-Fluent ([45]). The use of complex software is not easy, where operators need to have a good knowledge in thermodynamics, climatology, aerodynamics, materials science and informatics. A number of researchers used the software to simulate the effect of the configuration of urban space and surface material on the impact of heat in the urban area. There are also those who carry out field measurements to know the effect of pavement material in downtown on the local microclimate [17],[26],[19],[46]. In addition there are also researchers who performed studies based on remote sensing information (satellite images) by applying GIS software for analysis and graphical visualization in order to describe the heat emission of the area due to urban spatial configuration [5],[6],[7],[8],[16],[18],[20], [22],[30].

Formulations or equations of physics and mathematics that be used in a computer program in this context, have been integrated in a modelling application system. The user will not need to care whatever the formula is. What is important is that after the input process is carried out there are results that come out in the form of numbers, maps, graphs, and attractive color images. That's what users do to make simulations. The formulas that applied into the commercial software are in general physical equations which are solved by a high level of mathematical solution (integral equation, differential equation, iteration, matrix operation, etc.). The software users, consisting of architects practitioners, teaching staff, urban designers, and students generally do not know well about the physical and mathematical formulations. The equations mostly consist of thermodynamics, fluid mechanics, climatology, accompanied by mathematical solutions in the form of finite difference and finite element. There are also graphic informatics knowledge that converts numeric information into images with varying color structures (chromatography). Therefore, the commercial software is generally expensive, many of which are not affordable by architecture students to use as their study tools.

The aim of this study is to provide architects and urban designers with a basic understanding of the principles of heat transfer in the urban context. The formulas presented in this paper are simple equations, but with an adequate tolerance. So that it can be implemented in a spread sheet format independently by architects and architecture students. This study is limited to the matter of radiative temperatures and thermal emissions that occur in urban areas due to the application of an urban spatial regulation and building configuration. By applying these formulas, it will be easily made a simple simulation, so that it can be useful for making decisions on the imposition of a variable delineation and parameters in urban design, without depending on commercial software. LST (Land Surface Temperature) or the average horizontal surface radiation temperature of an urban area can be predicted quickly by a simple method with adequate accuracy.

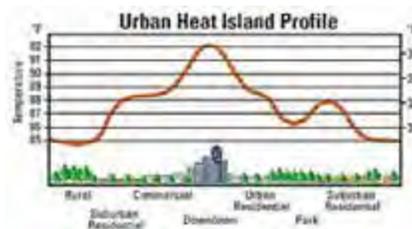


Figure.1. General temperature profile of UHI (Source:EPA)

The term Urban Heat Island (UHI) always attracts the attention of urban planners and designers. In general the definition of UHI is a condition of heat difference in an urban area compared to a rural area. Why say “island”, because it can be made horizontal contour lines of heat that are like forming an image of an “island”. Vertically, the nature of heat that differs from one point to another can form graphical lines that go uphill in urban areas and down again in rural areas (Fig. 1). Changes or climate dynamics in urban built areas can be seen or observed based on a horizontal view consisting of three scales, namely: Microscale, Local scale and Mesoscale. Whereas in the vertical view can be distinguished on Urban Boundary Layer Scale, and Urban Canopy Layer [2]. Heat emission from a type or land surface function, can increase the average radiation temperature of urban areas, thus affecting thermal comfort for humans in outdoor space, as well as increasing global warming on a broader scale. The authors and other researchers also pay attention to the radiative temperature as the main variable in determining the level of thermal comfort for outdoor activities [27],[29],[31],[32],[33],[34],[40],[42]. The temperature increases that caused by UHI has also added effects on heat-related illness such as heat stroke which is a serious health [3]. So through the study it is produced a simple method to predict the average magnitude of the temperature of outdoor radiation, so that it can provide input for the development of outdoor comfort and human thermal health studies. Beside there are also researchers who interested in surface temperature study for development of solar panel technology and material [39]

METHODOLOGY

Figure 2 explains the flowchart of the algorithm to calculate the surface radiative heat of a UHI. As the output is the surface temperature of the horizontal plane which causes an increase in the average temperature in the microclimate. In addition, we can calculate the amount of heat energy flux emitted into the atmosphere that causes an increase UHI. In the first stage, spatial and building-mass configuration regulations regarding BCR, FAR, GAR and BD need to be identified in a delineated urban area. Furthermore, the calculation of the area of the road, pavement yard, greening of roads and parks, as well as greening of the yard, and rooftop area (Fig.3). Each of these surfaces emits heat due to thermal properties of the material and because of the high intensity of solar radiation.

The general approximative equation for calculating the surface temperature of a material in a steady state (thermal balance) is ([21],[25], [47],[49]):

$$t_{sa} = t_a + \frac{(G\alpha - \phi)}{h} \tag{Eq.1}$$

where

t_{sa} : surface temperature (sol-air temperature)

t_a : air temperature

G: Global radiation from sun

a: Absorption (thermal) coefficient

j: Reflected energy due to radiation budget

h: Heat transfer coefficient

$\phi = 90 \text{ W/m}^2$ when the sun is upright vertically on a plane and if there are no clouds, 20 W/m^2 if there are clouds, 50 W/m^2 if in between [25]. $\phi = 0 \text{ W/m}^2$ for vertical wall.

And :

$$h = h_r + h_c + h_{ev} \tag{Eq.2}$$

Where:

h_r : radiative heat exchange coefficient

h_c : convective heat exchange coefficient

h_{ev} : evaporative heat exchange coefficient

t_{sa} is not a true surface temperature. It is a notional sol-air temperature which is the driving force of the heat flow [47]. It is not simple to obtain real value of surface temperature (t_s) through a direct equation because it is related to heat capacity, thermal inertia and other thermal properties of each type of material. A mathematical solution with differential equation should be used

to get a fine result of t_s . Therefore the simple calculation of t_{sa} is an approximation to the true t_s . Korhonen [28] has compared the results of t_{sa} calculations and surface temperature measurements with an average difference less than 15%.

The equation of t_{sa} expresses the dominance of the influence of solar radiation, which is short-wave radiation. While long-wave radiation in this case is neglected, because if there is sun, the dominant influence is from solar radiation. If there is no sun, then the long wave radiation which contributes to change the value of t_{sa} [48].

In the mechanism of heat transfer between the surface environment of outdoor space and its surroundings, there is heat exchange process in which the quantity depends on the value of the heat exchange coefficients. These coefficients include radiative, convective, and evaporative heat exchange coefficients. The heat energy flux between the surface of the plane with the outdoor air depends on the magnitude of the external surface temperature (t_s), outside air temperature (t_a), convective heat transfer coefficient (h_c) radiative heat transfer coefficient (h_r). Since the location is in humid tropical climate, where quantity of air humidity are to be considered in the evaporation energy process, then an evaporative heat energy flux is to be implemented, in which consequently also depends on a number of evaporative heat transfer coefficient, h_{ev} .

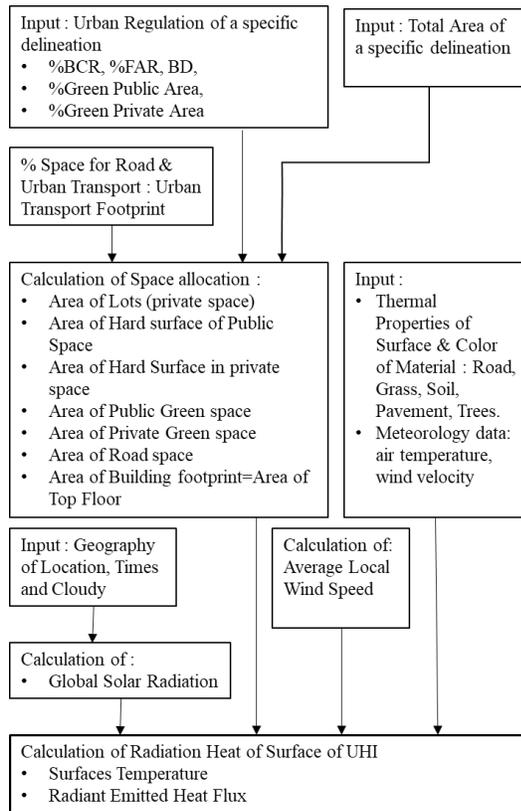


Figure.2. Flowchart of the calculation model

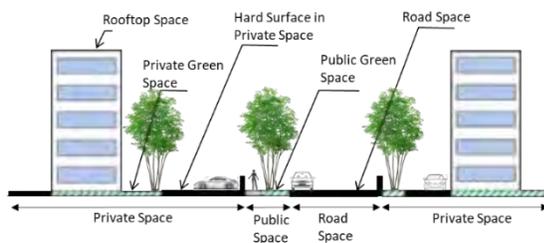


Figure.3. Profile of urban spatial function

Table.1. List of variables for spatial equation

| | | |
|---|-------|--------------------------------------|
| Total Land Area | LA | = Given (m ²) |
| Percentage of Public Green Space | P1 | = Given (%) |
| Percentage of Private Green Space | P2 | = Given (%) |
| Percentage of Road & Circulation Space | P3 | = Given (%) |
| Building Coverage Ratio (BCR) | P4 | = Given (%) |
| Floor Area Ratio (FAR) | P5 | = Given (%) |
| Maximum Building Density of Area | BD | = Given (mass/ha) |
| Maximum Building Density at Lot | BL | = Given (mass/lot) |
| Ratio of Length to Width of Building Mass | RB | = Given (integer (L : W) (ex 1 : 2)) |
| Floor to Floor Height | FH | = Given (m) |
| Window to Wall Ratio of North & South Façade | WWN | = Given (%) |
| Window to Wall Ratio of East & West Façade | WWE | = Given (%) |
| Percentage of Total Lots Area | P6 | = 1-P1-P3 (%) |
| Percentage of Total Area of Private Hard Land Surface | P7 | = P6-P2-(P4 x P6) (%) |
| Total number Building masses | NB | = (LA/10000) x BD |
| Percentage of Mass Building Footprints | BF | = P6 x P4 (%) |
| Total Floor Area of Building Mass | BA | = P5 x P6 x LA (m ²) |
| Maximum Floor Numbers | FN | = BA / (BF x LA) |
| Lot Density | LD | = (P6 x LA) / LA |
| Number of Lot | NL | = NB/BL |
| Area Each Lot | ALT | = (P6 x LA) / NL (m ²) |
| Total Area of Public Green Space | PGA | = P1 x LA (m ²) |
| Total Area of Road | RDA | = P3 x LA (m ²) |
| Total Area of Top Floors | TFA | = BF x LA (m ²) |
| Total Area of Private Green Space | PVGA | = P2 x LA (m ²) |
| Total Area of Private Hard Land Surface | HAD | = P7 x LA (m ²) |
| Area of Ground Floor of Each Building Mass | GFA | = (BF x LA)/NB (m ²) |
| Area of Hard Surface at Lot | HDL | = P7 x P4 x ALT (m ²) |
| Percentage of Hard Surface at Lot | PHDL | = HDL/ALT (%) |
| Green Area Ratio at Lot | GRAL | = 1-PHDL-P4 (%) |
| Area of Green Space at Each Lot | AGRAL | = GRAL x ALT (m ²) |
| Width of Each Building Mass | WL | = (SQRT(GFA/WL)) (m) |
| Length of Each Building Mass | LL | = (L / W) x WL (m) |
| North Façade Area of Each Building Mass | FNA | = LL x FH x FN (m ²) |
| South Façade Area of Each Building Mass | FSA | = FNA (m ²) |
| East Façade Area of Each Building Mass | FEA | = WL x FH x FN (m ²) |
| West Façade Area of Each Building Mass | FWA | = FEA (m ²) |
| Note : SQRT= Square root | | |

As for the Indonesian standard, SNI-6389:2011, the value of h_c of outside wall is 22.73 W/m²K. Since some variation of h_c , therefore, its application requires such complete information, by looking at the position of the wall, the type of convection whether the type of forced or natural convection, and consideration of the properties of material.

Cui Y [38] conducted an experiment to obtain comprehensive heat transfer coefficient for the case of the outdoor surface walls of buildings located in tropical islands. The results show that the total heat transfer coefficient, which is the sum of h_c , h_e and h_r , varies from 33.4 W/(m²K) and 38.9 W/(m²K), depending on summer or rainy season conditions, and the average h_{ev} is 5.2 W/m²K.

For case of a flat outdoor surface, Shao J et al [37] has conducted studies by means of experimentation to obtain value of h_c . From experimental study it was obtained a regression equation which is the relationship between h_c and wind speed, where $h_c = 7.64v + 2.05$, where v is wind speed that is measured at an altitude 1.6m from the surface. Value of h_r is vary from 3.37 to 4.46 W/m²K, depending on cloudy level of the sky [49],[41]. So the h_c coefficient depends on the wind speed at an altitude and its local situation. In general the wind speed data from the meteorological station is the results of measurement at an altitude 10 meters (as H_{ref}), located in the suburbs where the building density is not high. An approximative calculation of wind speed at a height in a typically site can be done by using the Hellmann power law model [50].

$$\frac{v_h}{v_r} = \left(\frac{H_h}{H_r}\right)^\beta \tag{Eq.3}$$

Where:

- v_h : wind speed at h height at certain location (m/s)
- v_r : wind speed data from meteorological station (m/s)
- H_r : Height of wind speed measurement at meteorological station (m)
- H_h : Height of location of case (m)
- β : Friction coefficient (Table.2)

Table.2. Friction coefficient for wind speed calculation

| Landscape type | Friction coefficient, β |
|---------------------------------------|-------------------------------|
| Lakes, Ocean and smooth hard ground | 0.1 |
| Grasslands (ground level) | 0.15 |
| Tall crops, hedges and shrubs | 0.2 |
| Heavily forested land | 0.25 |
| Small town with some trees and shrubs | 0.3 |
| City areas with high-rise buildings | 0.4 |

If there are many surfaces with different t_{sa} , (Fig.5) then to get an average t_{sa} can be approached by calculating the average proportionally according to the surface area (A_n), so that:

$$t_{sa-average} = \frac{\sum A_n t_{sa-n}}{\sum A_n} \tag{Eq.4}$$

If the surface temperature of the material is known with this simple formulation, then the amount of radiant heat flux (Fig.4) can be calculated with Stefan Boltzman’s basic formula:

$$Q_n = \sigma \epsilon_n A_n T_n^4, \quad Q_T = \sum Q_n \tag{Eq.5}$$

Following the algorithm as in Fig.2, the calculations consist of:

- Space area allocation of the spatial functions (road area, green area, building footprint area, rooftop area,..etc)
- Global radiation of sun
- Wind velocity at site
- Horizontal (Land) surface temperature
- Heat radiation emitted by surfaces

The inputs required are:

- a. Input from urban regulation :
 - BCR: Building Coverage Ratio (Building Footprint Ratio); percentage of footprint area to land private area (lots)
 - FAR: Floor Area Ratio; percentage of total floor area to land private area (lots)
 - PvGAR: Private Green Area Ratio; percentage of private green space area to land area
 - PbGAR: Public Green Area; percentage of public green space area to land area
 - BD: Building Density; numbers of building mass to land area
 - Percentage of road and circulation space (if any)
 - Wall to Window Ratio of building mass (if any)
- b. Input from data meteorology, and geographical location
 - Air temperature, wind velocity, latitude
- c. Input thermal properties of surface materials:
 - Absorptivity of material and its color
 - Emissivity of material

Table.3. Thermal properties of material for calculation

| Material | emissivity | thermal absorptivity | |
|--|------------|----------------------|-------|
| | | material | color |
| Asphalt (Road) | 0.9 | 0.8 | 0.8 |
| Paving (Trottoir & Parking) | 0.9 | 0.5 | 0.5 |
| Concrete (Top Floor) | 0.9 | 0.5 | 0.5 |
| Brickwork & Plaster (Wall of Buildings) | 0.9 | 0.7 | 0.5 |
| Greenery (Trees) | 0.9 | 0.2 | 0.5 |

Calculations of sun radiation on horizontal surface may refer to Sfeir et al [35], as follow:

Very clear sky condition: $G_H = 1130 (\sin hs)^{1.15}$ (Eq.6)

Moderate visibility of sky: $G_H = 1080 (\sin hs)^{1.22}$ (Eq.7)

Sky is rather dim: $G_H = 995 (\sin hs)^{1.25}$ (Eq.8)

Where hs is altitude of sun angle (degree)

RESULTS AND DISCUSSION

By using the above equation model, simulation can be performed to determine the effect of building configuration and urban spatial regulation on outdoor heat exchanges.

Effect of Green Area and Pavement

Most city regulations govern BCR, FAR and some even regulate Building Footprint. Space of green area is expressed by a coefficient of GAR (Green Area Ratio) and/ or GOS (Green Open Space). Basic law of spatial balance is when the larger area of green space, the opposite will be the smaller area of pavement. Simulations were made by making variations in the area of green space with amount of GAR from 30% to 100%. GAR 30% represents as a downtown area, while GAR 100% is as forest area. If GAR is 30%, then the pavement area is 70%.

The pavement area consists of road with asphalt material and also parking lot with pavingstone material. The green area consist of private and public spaces. Objective of simulation was to find out the value of surface temperature in tropical location when the sun is vertically to the land as a maximum by applying global radiation of 900 W/m^2 , and the air temperature is set 31 deg.C . Thermal properties of material as shown in the Table.3, where emissivity and absorptivity coefficient of hard material and greenery are also refer to other authors ([9],[11],[14],[19],[23],[24],[36]). The results show that in general, an increase in surface temperature is proportionally to the reduction in green area (Fig. 6 and 7). By using this simulation method, it can even be known the value of average maximum surface temperature that will be produced by a built environmental design. In this case the results were obtained that the average surface temperature can reach more than 43 deg.C , with the composition of urban space where the green area is 40%, top floor area is 24% (same as the Building Footprint), private space pavement area is 17%, road area is 25%. (Table .4). The average surface temperature of urban land will be higher than air temperature due to the influence of heat emission from the hard surface material with high emission coefficients. There have been many studies that prove that in UHA (Urban High Area) area where there is a lot of pavement, has an impact on the high LST. Even the influence of the pavement can cause high surface temperatures during the day, and can reach more than 40 deg.C in a tropical city ([5],[6],[8],[10],[16],[18],[20],[24])

Figure 8 shows the daily profile of LST changes, where during the daytime there is a temperature jump that is higher than the air temperature. Whereas at night when the sun is absent, the surface temperature will be relatively the same as the air temperature. This tendency is also shown by the studies of other researchers [22],[26],[44].

Comparison to the Other Studies that used Satellite Imaging

It is common to find color picture representing scale of LST. The picture is generally done by an informatic image processing from satellite data and then be analysed by using GIS software. The results of LST calculations using the model in this study, are to be compared to the results of other studies through satellite photos, among others, with a study by using Terra/Aqua Satellite with Modis (Moderate Resolution Imaging Spectroradiometer) [7]. Simulations were made to find out the maximum LST for the Urban High Area case in 3 tropical cities in Indonesia, namely in Surabaya, Bandung and Semarang. Assume that in the High Urban Area, where BCR is 60%, GOS is actually 30%, GAR 30%, and Road Area is 20%. The comparison results of the LST calculation are tabulated in Table.5. which shows that there is a similarity with the Maximum LST value by means of satellite imaging. Even though there are differences, is still relatively tolerable at only around 10%. In the city of Bandung, the maximum LST reached 44.5 deg C (according to satellite photo results), while the simulation method obtained value of 48.13 deg C . In Surabaya there is a difference of 5.3 deg C , whereas in Semarang City, the difference is 4.7 deg C . The differences may also occur caused by the use of emissivity value, heat absorption coefficient and spatial configurations that are not exactly the same as those applied by the comparator study. Based on the results of the comparison, it can be said that this simple calculation model can be declared valid so that it can be used as a simulation tool to predict the impact of urban spatial configuration on LST.

Influence of Green Roof

In urban areas, the use of green roofs is intended to reduce the heat of UHI. A study using the ENVI.met software was carried out to determine changes in UHI due to the use of green roofs in tropical areas which can reduce temperatures around 5 deg C [15]. By using simple formulation model in this study, a simulation can also be carried out to determine the role of the green roof in reducing heat emission. The results show that Green Roof can reduce to more than 4 deg C with a BCR condition of

60%. If green roof is not used, then the roof material which is constructed by using concrete, can emit a considerable heat radiation. However, when using a green roof, the position of concrete is replaced by vegetation that is able to withstand the rate of radiant heat. When green roof in urban areas are applied with BCR of just 30%, the effect is not significant in reducing the surface temperature of land cover (Table.6). This results show like a minimum limit of BCR when apply green roof. This is logical, when BCR is greater, then get more opportunity of available area for greening and that to be able to withstand the rate of radiant heat energy of surfaces.

Table.4. Result of simulation to find out LST

| Building Coverage Ratio at Lot | Building Footprint at Urban Area | Green Open Space at Urban Area | Pavement Private Space Ratio at Urban Area | Road-Urban Traffic Space | Average Land Surface Temperature (deg C) |
|--------------------------------|----------------------------------|--------------------------------|--|--------------------------|--|
| 0% | 0 | 100% | 0% | 0% | 31.0 |
| 20% | 3.0% | 90% | 2.0% | 5% | 33.1 |
| 30% | 6.0% | 85% | 4.0% | 5% | 33.9 |
| 40% | 10.0% | 80% | 5.0% | 5% | 34.4 |
| 50% | 15.0% | 75% | 5.0% | 5% | 34.9 |
| 50% | 17.5% | 60% | 7.5% | 15% | 38.5 |
| 60% | 27.0% | 50% | 8.0% | 15% | 39.4 |
| 60% | 33.0% | 40% | 12.0% | 15% | 40.8 |
| 60% | 36.0% | 30% | 14.0% | 20% | 43.0 |
| 40% | 24.0% | 40% | 16.0% | 20% | 42.5 |
| 40% | 24.0% | 40% | 16.0% | 20% | 42.5 |
| 40% | 18.0% | 40% | 17.0% | 25% | 43.7 |
| 40% | 16.0% | 50% | 14.0% | 20% | 41.4 |
| 40% | 12.0% | 60% | 8.0% | 20% | 39.6 |
| 40% | 14.0% | 60% | 11.0% | 15% | 39.1 |
| 40% | 10.0% | 70% | 5.0% | 15% | 37.3 |
| 30% | 7.5% | 70% | 7.5% | 15% | 37.7 |
| 30% | 9.0% | 70% | 11.0% | 10% | 37.3 |
| 30% | 6.0% | 80% | 4.0% | 10% | 35.3 |
| 20% | 3.0% | 85% | 2.0% | 10% | 34.6 |
| 10% | 1.5% | 85% | 3.5% | 10% | 34.8 |
| 10% | 1.5% | 90% | 3.5% | 5% | 33.4 |
| 0% | 0.0% | 100% | 0.0% | 0% | 31.0 |

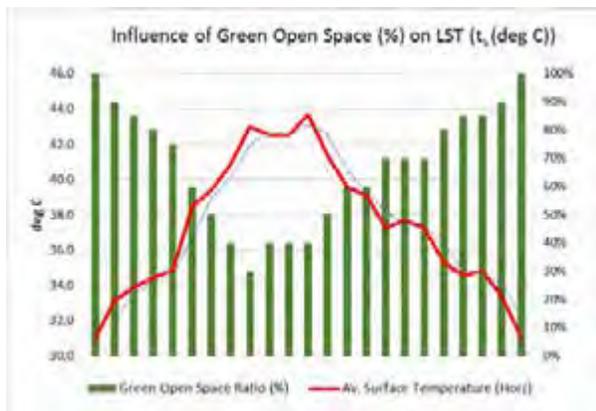


Figure. 6. Influence of Green Open Space

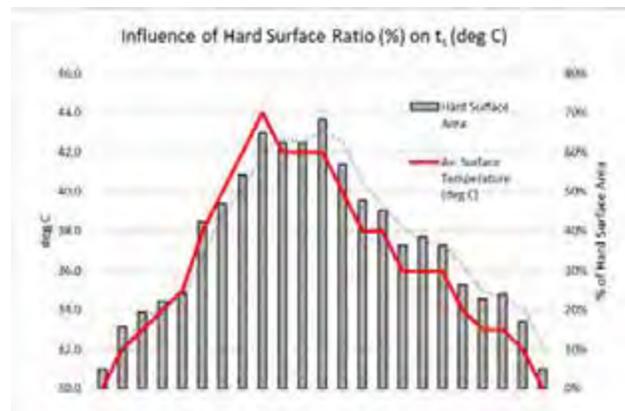


Figure.7. Influence of pavement area

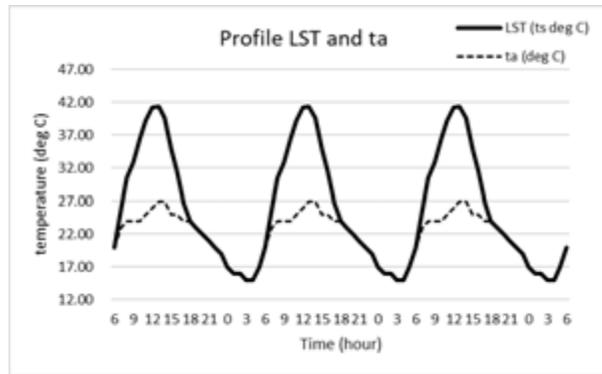


Figure.8. Daily profile of surface and air temperature by calculation

Table.5. Comparison of the result with other study

| City | Lat | t_a (max) | G_h | LST (max) | |
|----------|------|-------------|-------|------------------|--------------------|
| | | | | This Calculation | Satellite Imaging* |
| | | | | deg C | deg C |
| Bandung | -6.9 | 33.2 | 990 | 48.13 | 44.50 |
| Surabaya | -7.0 | 36.2 | 1021 | 52.40 | 47.10 |
| Semarang | -7.3 | 35 | 1011 | 51.20 | 46.50 |

Urban Space Configuration (assumption for calculation) :

BCR: 60%

GOS: 30%

GAR: 30%

Road Space: 20%

* K.D.Sukowati – 2009 [7]

Table.6. Influence of Green Roof on average Land Surface Temperature

| BCR | LST (max), deg C | | Dif. |
|-----|--------------------|-----------------|------|
| | Without Green Roof | With Green Roof | |
| 60% | 52.4 | 47.9 | 4.5 |
| 50% | 51.5 | 48.3 | 3.2 |
| 40% | 51.9 | 49.4 | 2.5 |
| 30% | 52.3 | 50.4 | 1.9 |

CONCLUSION

Urban spatial and building configuration regulations need to be evaluated from the view point of UHI's perspective. The increase in UHI may also be caused due to inappropriate regulation of a spatial urban area. Each spatial variable in the urban zoning and structure can be a thermal trigger in global warming matters.

Through this study a simple calculation algorithm has been applied to evaluate the urban spatial risk to the possibility of UHI increase. The results of the calculation of the maximum average surface temperature (LST) have been compared with other studies conducted using satellite images, and show a moderate difference.

This simple calculation model can be used independently by architecture students, architect practitioners, urban designers, in order to make an evaluation of the design of a built environment on UHI, without depending on expensive commercial software.

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THE OAKLAND ECOBLOCK: A CASE STUDY IN ACCELERATING THE DEPLOYMENT OF ADVANCED ENERGY COMMUNITIES

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ABSTRACT

The Oakland EcoBlock is a planning project that will retrofit an existing residential city block to change resource use and energy production at the block scale. This scale is believed to be more resource use efficient than the individual house scale, using less energy and water, and in turn, reducing greenhouse gas (GHG) production. Little is known about how action at the block scale transforms the consumptive characteristics of America's existing urban and suburban residential landscape. The study contributes a detailed description of the planning process for a block scale project that seeks to address today's challenges of energy and water scarcity, greenhouse gas emissions, and enhanced resilience. Drawing on interview data with members of the Oakland EcoBlock project team in the San Francisco Bay Area of California, USA, the project team identified key decision making points and factors that informed this residential retrofit project. Interview narratives reveal a high level of complexity between the technical and social elements of the project. Descriptions suggest that identifying the most effective scale for a residential retrofit is linked to planning, modeling, simulating, and demonstrating a specific project. In addition, initiatives to deploy and scale up retrofit measures will be affected by the success of the project team to secure external support, develop generalizable approaches, and create compelling narratives. The study concludes that social barriers, on balance, outweigh technical limitations. In addition, cost, and to a lesser degree valuation, is a primary input for critical decision making points throughout the project planning process.

KEYWORDS

Ecocities, Residential Retrofit, Resilience, Planning, Oakland, California

INTRODUCTION

This paper documents the process by which the interdisciplinary project team arrived at a high performance design, one that showed promise to deliver energy, water, and costs savings, using integrated systems and components for an existing city block. It also discusses the design development documents, specifications and cost estimates, and a schematic monitoring plan used for the project. It documents key decision making points in the critical path of the project and the key constraints that informed them. The case study is intended to characterize the transformative nature of the Oakland EcoBlock effort for a broad audience: researchers, residents, practitioners, academics, state leaders, regulatory officials, and community leaders.

The Oakland EcoBlock is an academic research project that considers the potential of a residential block in Oakland, California. The planning project brought together residents of a local neighborhood block and a multidisciplinary project team of engineers, urban designers, lawyers, social scientists, and policy experts. Devised in partnership with the local community, the project applies a whole systems design approach to retrofitting the block from high energy and water dependency to the lowest energy and water footprint possible—transforming an obsolete, resource wasteful model into a resilient design that guarantees residents' long term comfort and security.

In this study, the project team undertook a survey to identify the strengths and weaknesses of the EcoBlock approach. More specifically, how the project team develops an understanding of whether retrofitting the block scale is more efficient and cost effective (because it combines the flows and efficiencies across multiple units) than the individual house scale in achieving maximum renewable energy, water conservation, and local wastewater treatment and reuse is answered.

The project was supported by a two-year Phase I planning grant provided by the California Energy Commission through their Electric Program Investment Charge (EPIC) Grant 15-312. The project team formed in 2014 and included experts with decades of previous work on neighborhood scale sustainability projects. The grant was submitted in December of 2015 with a Notice of Proposed Award in March 2016 and concluded in March 2018. In January 2019, the project was awarded a four-year Phase II demonstration grant as part of the second phase of the EPIC program and will continue through 2023 (<https://ecoblock.berkeley.edu/>).

EXISTING CONDITIONS

The Phase I study site is in the Golden Gate Neighborhood of Oakland, California in the United States. The block has a uniform land use which is entirely residential. However, commercial uses are nearby, lining San Pablo Avenue to the east. The building types include 25 wood frame single family homes, one wood frame eight unit multifamily residential building and one concrete 11 unit multifamily residential building.

POLITICS AND GOVERNANCE OF CLIMATE CHANGE

The politics and governance of climate change at the city and subnational level have been gaining traction in the last two decades. In the recent report by the International Panel on Climate Change (IPCC), *Climate Change 2014: Impacts, Adaptation, and Vulnerability*, local governments were, for the first time, recognized as actors in efforts to mount a climate response (IPCC 2014). Despite an entire chapter (Chapter 8) devoted to urban areas, efforts have remained context specific and varied (Joss 2011; Foss 2016).

Even though city and subnational experience addressing climate change has been uneven, urban environments are still viewed as an important site of greenhouse gas (GHG) reduction because cities are sites of high consumption and waste generation with a degree of local control. In addition, city governments have shown that they are capable of taking on complex sustainability agendas and can coordinate key actors (Bulkeley and Betsill 2013). Finally, local authorities now have experience addressing these types of issues and can undertake innovative measures, underpinning policy experimentation and demonstration projects. However, limitations still exist to the authority and technical competencies of governmental actors, and constraints continue to hamper the ways in which urban development and transportation problems are defined and discussed (Bulkeley et al. 2015).

As local governments are recognized alongside nation-states for addressing climate change, public participation and cultural framing have gained importance. A significant body of literature is devoted to developing typologies of citizen participation associated with urban climate change adaptation with respect to engagement, public participation, and civic capacity (Sarzynski 2015). Different trajectories of city sustainability plans have been chronicled to show the importance of public participation and cultural framing (Foss 2016). This work reveals that citizen steering models, public-private partnerships, and the nonprofit sector are essential to understanding the network of multiple actors and hybrid arrangements working at the local level (Joss 2011; Broto 2017).

Neighborhood/Urban/Regional Planning for Sustainability and Climate Change

Climate change activity forwarded by nation-states has traditionally focused on GHG emitting facilities, such as power plants, or has been propelled by societal questions around environmental justice or vulnerability, as opposed to concerns with climate change directly (Cushing et al. 2016). However, urban scale mitigation and adaptation of climate change can address cities that have an intense demand for resources (estimated to be responsible for 60 to 80 percent of world energy use), while at the same time, preserve social, environmental, and health service that occur in urban areas. Such efforts also deliver significant co-benefits such as cleaner air, green jobs, urban environmental quality, and water and energy security. Action at the local level is increasingly viewed as an effective scale for climate change action, undertaken by a variety of actors and driven by exposure to the effects of sea level rise and natural hazards (Hallegatte and Corfee-Morlot 2011).

Cities are looking for ways to implement immediate and lasting transformation at the local scale. Regional, urban, and neighborhood efforts are increasingly finding that technology alone is not likely to result in broader societal transformations (Bouteligier 2010). Pilot projects are often criticized as “techno fixes” that do not provide information about best practices and omit social aspects, particularly learning and social organization, that are crucial to lasting change. In addition, municipal governance, including scale, organization, and culture, are highly influential (Foss and Howard 2015; Dierwechter and Wessells 2013). Finally, implementation of potential risk mitigation strategies has been shown to be limited by institutional constraints and barriers (Hallegatte and Corfee-Morlot 2011).

The United States has traditionally looked to power plants, public facilities, and policy to address climate change, with Europe and Asia pursuing a greater number of ecodistrict development projects (Fu and Zhang 2017; Fitzgerald and Lenhart 2016; Fraker 2013). In Sweden and Germany, local authorities often retain ownership of land, granting only the right to develop, or acting as the developer themselves, while in China local authorities commonly lead the pursuit of smart and ecocities (Fraker 2013; Fu and Zhang 2017). The United States has had far fewer neighborhood scale ecodistrict development projects and has shown reluctance to tamper with private land ownership and development markets.

In general, neighborhood scale sustainability transitions (e.g., ecodistricts, transition towns) have shown that change is happening at the household level and control over broader community systems remains elusive. They also have shown that there is an inherent tension between taking a mainstream stance needed for governmental collaboration and local funding and taking a radical stance necessary for transformational change that targets modes of consumption and mobility, or root political and economic drivers (Forrest and Wiek 2015). However, the city scale has been found to have opportunities to implement no regrets strategies that address climate and provide multiple community benefits. More careful cost benefit analysis and cost effective planning strategies at the local scale in routine planning have shown promise to also address climate change impacts (Hallegatte and Corfee-Morlot 2011).

Urban Political Ecology

Questions about the equity and social justice dimensions of ecodistrict developments are frequently raised. EcoBlocks and associated typologies of ecodistricts, ecocities, and ecoregions are often criticized for merely attempting to create an ecologically secure gated community, rather than contributing to a more collective notion of planetary security. The literature suggests several strategies to avoid the creation of premium ecological enclaves calling for the discussion of resource futures with users, balanced sociotechnical responses, retrofitting the existing city (in addition to new builds), emphasizing questions about interdependencies (avoiding security for only some), and encouraging debate about the new style of urbanism offered by the ecological city (Hodson and Marvin 2010).

DEVELOPMENT HISTORY

The Oakland EcoBlock project focuses on a block that developed as railroads crossed the United States and electrified transportation became commonplace. It was part of a prosperous city enabled by the “Age of the Trolley”—a time when an emerging middle class could begin to commute to employment centers and live beyond the city’s original borders. The prosperous city was also the consumptive city, consuming land, and with the advent of electrification, plumbing, and the internal combustion engine, water and energy.

The historical development of Oakland shows neighborhood block development coincident with national and regional railroads and electrified streets. Developed as a typical American rail or streetcar suburb, the current neighborhood is in the heart of a thriving community with only vestiges of its rail history visible. Blocks like this can be found in every major city throughout the United States and today they are experiencing a renaissance as walkable neighborhoods and alternatives to the automobile are increasing in popularity. The Oakland EcoBlock provides a significant opportunity to contribute to the rebirth of the area, only reimagined as a place that will radically reduce climate change impacts and enhance community resiliency (Callaway et al. 2015).

COMPARABLE CASE STUDIES

The following table summarizes 10 case studies of comparable projects (Table 1). The project team examined three case studies (Regen Villages, Bayview GLEN Snap, and Sun Valley EcoDistrict) for their similarities with the goals and aims of the Oakland EcoBlock project, and an additional three cases (UC Berkeley Global Campus, ParkMerced, India Basin) are profiled because they are district scale developments in the Bay Area with strong environmental goals and aims. In addition, four cases of interest (Smart City Shioashya, N Street Cohousing, Hydebygade Block, Transition Zero) were included.

Table 1: Projects Comparable to the Oakland EcoBlock

| No. | NAME | LOCATION | PROJECT TYPE | CONST TYPE | SITE (AC) | UNITS (No.) | DATE |
|-----|---------------------------|----------------------------|----------------------------|------------|-----------|-------------|-------------------|
| 1 | Regen Villages | Almere, Netherlands | New Town, Residential | New | 3.9 | 25 | 2016 Ongoing |
| 2 | Bayview Glen SNAP | Toronto and Region, Canada | Urban Renewal, Residential | Retrofit | Varies | Varies | 2016 Ongoing |
| 3 | Sun Valley EcoDistrict | Denver, CO, USA | Mixed use Residential | Mixed | 100.0 | 1,083 | Ongoing |
| 4 | UC Berkeley Global Campus | Richmond, CA, USA | Research Campus | New | 134.0 | 0 | 2016 Vision Plan |
| 5 | ParkMerced | San Francisco, CA, USA | Mixed use Residential | Mixed | 152.0 | 3,221 | 2012 Vision Plan |
| 6 | India Basin | San Francisco, CA, USA | Mixed use Residential | New | 23.0 | 1,240 | 2018 Concept Plan |
| 7 | Smart City Shioashya | Hyogo, Japan | Residential | New | 29.7 | 500 | 2012 Launch |
| 8 | N Street Cohousing | Davis, CA, USA | Residential | Mixed | 3.0 | 19 | 1999 |
| 9 | Hydebygade Block | Copenhagen, Denmark | Residential | Retrofit | 35.0 | 350 | 1996 |
| 10 | Transition Zero | Nottingham, UK | Residential | Retrofit | 10.0 | 9 | 2017 |

METHODOLOGY

The Oakland EcoBlock grant proposed a case study research method to yield insight as to how a single, block scale response might be applied to multiple blocks, resulting in a transformation in energy and water use in existing neighborhoods.

The research employed an embedded (multiple unit of analysis) single case study design, examining a single block in the City of Oakland, California. The units of analysis included eight key topics that were listed in an interview script. In addition to interviews, the research utilized documentation and direct observation as additional data sources to describe the development history and current conditions of the block.

Utilizing the existing Oakland EcoBlock contact list, the researcher identified 30 project team members to be interviewed over a three month period (August–October 2017). Eighteen interviews lasting between one half hour to one hour were completed with project team members. Eight interviews were conducted in person, and the other 10 were completed over the phone. Using a standardized script, the researcher asked questions about these topics and administered standardized interviews to provide comparable information. A discussion of the results is included in subsequent sections of this document.

RESULTS

Oakland EcoBlock project team members provided responses on eight topics discussed below. Each section highlights key considerations and best methods for retrofitting an existing residential city block.

Constraints and Processes

Project team members identified several utility constraints which the Oakland EcoBlock project would need to address for project success. First, the legal regime for utility service is set at the state level and structured for regional scale service provision. The California Public Utilities Commission (CPUC) laws and regulations are comprehensive and tailored for large-scale infrastructure. In addition, they apply broadly to any entity that provides energy to two or more persons. Respondents noted the current regulatory environment is burdensome for local or distributed energy generation systems (serving between two and one hundred individuals), and small systems are not likely to require the same level of regulatory oversight. Second, solar energy to multiple parties and across property lines or public rights-of-way, master metering, and on-site blackwater treatment are prohibited outright and barriers allowing reuse of graywater exist. Third, although it was unclear which electrical interconnection would be optimal, respondents noted that legal constraints likely exist here as well. Finally, team members identified the need for new legal agreements to address ownership of shared elements, potential liability, and insurance coverage to assure operations and maintenance of block scale energy and water systems into the future.

In contrast, respondents identified few planning and land use constraints for the project. Project team members noted consistency with state and city climate goals and acknowledged broad support from the City of Oakland. Respondents noted that, as a retrofit, pursuing regulatory exceptions to existing planning and entitlements processes where needed was a feasible project approach. For instance, the land use will remain residential, avoiding any change in use that would trigger local review. Respondents noted that the potential introduction of non-residential uses, such as the flywheel for energy storage or a living machine for water treatment, was permitted on an adjacent property zoned for light industrial/manufacturing use (a potential concern for neighborhoods zoned exclusively for residential land use). Despite the lack of constraints, several project team members indicated the time and resources needed to address all concerns and obtain city approvals is likely to be a limitation. An individual suggested that an Innovation District Overlay or Demonstration Zone, like those instituted in the communities of San Jose and Sacramento, might facilitate the city approvals process.

Project team members indicated that state policy calling for reductions to greenhouse gas emissions and local policies supportive of sustainability are helpful, as is the flexibility and supportiveness from local agencies such as the City of Oakland, East Bay Municipal Utility District, and Pacific Gas and Electric—all of whom provided staff time and data, attended meetings, characterized the existing systems, and participated in collaborative workshops. However, state regulatory processes for utilities hinder project planning, prioritizing a system that includes a regional scale grid and configuration of services around power plants. Finally, team members noted that all public processes are constrained by limited public budgets and a lack of financial incentives that can slow implementation even with robust planning and local support.

Community Engagement Processes

The project team interviews revealed that the highest priority for community engagement was to facilitate interaction with the community, both for participatory decision making and technical information exchange. Also important was the project team's ability to address community questions, such as the progress of the project, when construction might be undertaken, or whether subsidies or cost share would be provided. Few respondents thought that prioritizing guaranteed energy, water or cost savings or total support from homeowners and tenants should be emphasized. However, when asked how project team members would evaluate the success of the community process, several individuals noted that success could be evaluated based on support for the project, as exhibited by positive narratives at public meetings or owners and/or tenants electing to participate in the next phase of the project. Other indicators of success would be high levels of attendance at community meetings and providing residents with sufficient information for decision making.

Several respondents expressed concern that the community process for Phase I of the Oakland EcoBlock project should have taken place earlier and been more robust. The engagement process was seen as a missed opportunity to build trust and local advocacy for the project among the residents. Too often, community contact was structured as academic research, with a focus on protection for human research subjects, rather than community engagement. Finally, due to the technical nature of the project, some project team members felt it was important that the project respond directly to community needs, while others believed it was most important to focus on performance goals while listening to and understanding concerns.

Governance Framework

Little agreement existed among respondents when asked a question about which governance framework would facilitate the construction, maintenance, and operation of the project. The most common response was that a clear governance structure was needed, with a diversity of legal structures identified as potentially meeting the project's needs including, a cooperative, trust, community choice aggregation (CCA), utility, third-party developer, municipal department, or a homeowner's association (HOA). Despite the diversity of answers, the question of how long-term operation and maintenance would be undertaken was a significant component of the responses. Several individuals noted that a Community Facilities District (CFD) was an ideal mechanism to address the ongoing funding challenge of operations and maintenance for small-scale infrastructure.

Energy Efficiency, Electrical, and Water Issues and Opportunities

The project team guided the technical elements of the Oakland EcoBlock through three primary methods with two key roles. Respondents noted that most project team methods were to: provide data; assist with identifying the optimal infrastructure design; and/or identify precedents, examples or processes that could serve as models. Project team members also identified two unique roles, either as a project team facilitator that brought together academic and professional groups or a community facilitator who was responsible for conveying project team information to the block residents.

Most commonly, project team members noted estimated costs relative to technology, implementation, and scalability as a critical decision-making point. Respondents noted the tension between a research-driven project and the potential cost of implementation required for a demonstration project, acknowledging that there are many unknowns and elements that are difficult to quantify using traditional cost estimating methods. Other discussion topics included critical decision-making points, such as developing an effective community outreach process; balancing interrelated sustainability priorities; supporting capital costs associated with infrastructure; commitments to wholesale electrification; and project transferability.

The most significant deep energy retrofit issue that respondents identified was balancing the hard and soft costs of improving efficiency with the value of the improvements. Several noted that deep energy retrofits, such as adding insulation and high-performance windows within an existing home, may be disruptive, and other retrofits, such as a transition away from gas stoves to electric stoves may require owners to change their behavior. Relative to the electrical system, project team members identified the most significant issue as technology choices, such as decisions around the use of specialized components; a two-circuit system including both alternating and direct current; specific connection to the grid and the ability to provide or draw energy; the capacity and capability of energy storage; and the ability to integrate electric vehicle charging. In addition, they noted that the electrical systems being considered are relatively new and are likely to evolve rapidly over the next two to three years. Many respondents also identified balancing costs and value as an important issue for the electrical system.

When asked about the water system, project team members highlighted costs as the most important issue, particularly compared to the relatively low cost of water and the relatively high cost of water treatment and distribution infrastructure. Many respondents also highlighted the block versus regional-scale approach as a critical issue, noting that scale efficiencies for energy

and water varied based on the costs and configuration of each system, with early analysis suggesting that water efficiencies may be reached at scales greater than a single block.

The most common opportunity associated with deep energy retrofits that project team members identified was reduced energy costs, with quality of life and comfort also identified by multiple respondents. One individual noted that, although saving money was important for residents, most users were persuaded to undertake energy efficiency retrofits on the bases of comfort (temperature), safety (fewer pests), health (improved indoor air-quality), and sound transmission (quieter). Respondents also noted an opportunity to address state greenhouse gas and carbon reduction goals, with the associated focus on better performance driving resource conservation. For the electrical system, respondents identified resilience and reliability as the primary opportunity. They noted that redundancy created by local energy production and independence from the grid during an emergency can be a direct benefit for residents (particularly in an earthquake and wildfire-prone region). Leveraging local resources and access to renewable energy produced nearby, along with load management (for both use and securing preferential use rates) were also identified as important opportunities.

For water efficiency upgrades, project team members responded that the key opportunity is to conserve water, which will, in turn, heighten residents' awareness of it as a resource. Several individuals indicated that visible treatment and purification could also raise awareness about maintaining water quality. A variety of other benefits were identified, including showing how water use is linked to energy consumption; describing associated ecosystem benefits; and how conservation can provide water availability in times of drought.

Innovative Business Models

Most respondents answered that they had not assisted with the identification and development of business models but had contributed by building an understanding within the project team about the design and engineering landscape. A respondent described elements related to water re-use where they identified suppliers, described on-bill financing, structured agreements and financing, and described methods to leverage capital. Also, several respondents contributed peripherally to cost estimation, identifying long-term costs and/or pricing system components. Several project team members noted that they helped develop the business framework by brainstorming, identifying potential risks, or pushing back on costs.

Project team members were asked to consider a city-led model—as well as the possibility of other alternatives, such as a utility, third-party developer, or homeowner-led model. Respondents identified the biggest drawback to a city-led business model as a lack of municipal capacity and budgetary limits. They expressed concerns about a city's ability and/or willingness to take on the responsibility and associated liability of these critical functions. Several individuals did not believe the city would have the appetite or ability to provide the same level of service that is currently provided by a utility district or electric company. The project team members responded positively to a city's existing governance structure that already engages with codes and regulations and has authority over public rights-of-way. In addition, some respondents noted that the city shows interest in alternatives that the utility is slow to consider.

Within this discussion, project team members also expressed a diversity of opinions about the utility, third party developer, and homeowner-led business models. While some respondents noted that the utility has an enabling legislation, a corporate organization, energy knowledge, and technical expertise, they may be to profit focused, with little incentive to take on a more equity-driven model that could be offered by a municipality. Project team members noted that a third-party developer-led model could provide competent technical management, but that there may be no clear company structure or business incentive. Individuals considered the homeowner-led model attractive because it promoted grassroots involvement and community commitment, but at the same time, were wary of this structure because it relied too much on volunteer labor, lacked technical expertise, and was often perceived as parochial and/or overly burdensome to home ownership.

Design Documents and Specifications

Respondents on technical teams anticipated developing concept-level design, narratives, and specifications, and at the time of the survey, indicated that this work was currently in preliminary stages. Several respondents noted that they would not be creating these documents, but would need these materials to complete their analysis of project pros and cons. Most project team members indicated that the primary elements to describe in design documents should be details of the physical infrastructure. Respondents also noted that the design documents may include legal requirements and approaches, installation, testing requirements, quantitative performance characteristics, scope of alternatives, modifications to existing utilities, maintenance requirements, and homeowner responsibilities. Project team members made little distinction between the design documents and detailed description of design, materials, and the standard of workmanship commonly characterized as specifications.

Cost/Benefit

Project team members identified three key categories of costs and other types of potentially important cost considerations. First, they discussed hard costs, identifying building construction components for energy efficiency, photovoltaic equipment, electric vehicle charging, electrical conduit, hardware, and batteries. Second, respondents discussed soft costs, such as designs of the electrical system or water concepts. Third, multiple individuals also identified operations and maintenance costs as a key project cost category and noted that resident transactional costs, such as hours present at home and detailed conversations with contractors can be substantial.

Project team members consistently mentioned five categories of benefits suggesting a more unified concept of the project's potential despite the project team members' diverse expertise. The five key benefits of the project were: (1) greater sustainability and resilience, (2) greenhouse gas emission and carbon reduction, (3) scale efficiencies and more effective use of resources, (4) reduction in utility bills and associated cost control, (5) rapid technology development associated with proof of concept. Several other benefits identified included modernization, greater reliability, improved air quality, access to direct-current power, local control, faster deployment, social benefits associated with collective action, better living, and "doing the right thing."

Project team members were also asked to discuss why key assumptions were important when considering costs and benefits. The most common response was that full lifecycle costs must be considered, and too often, the picture of the full cost and/or value of project is inaccurate. Several respondents noted it is likely safe to assume that resident project improvements will go beyond cost savings because drivers, such as societal benefits and resource conservation, will be valued by residents, and the benefits (e.g., sense of well-being for upholding environmental values) may be difficult to quantify. Finally, project team members believed assumptions that energy and water rates will rise over time (due to a scarcity) and technology costs will fall (as markets become established) must be integrated into estimations. A dynamic understanding of project costs and benefits is required.

DISCUSSION

The analysis of the narratives emerging from the interviews with specific project team members revealed high levels of complexity between technical/utility/research elements and legal/political/community elements. The potential to promote a change in resource use and energy production at the block scale in an existing community remains experimental and challenging.

The planning process provided additional evidence that neighborhood scale sustainability projects with aspirations of transforming cities require a consistent theoretical basis and attention to data development. The Oakland EcoBlock prioritized water and energy systems, but at the same time, is silent on common ecological city variables such as waste, mixed uses, or compact/high density settlement patterns that potentially have significant effects on the consumption-based demand of a city block (Bayulken and Huisingh 2015; Thomson 2015). Despite a variety of variables not being addressed, the Oakland EcoBlock developed a consistent theoretical basis focused on major resource streams (water and energy captured, reduced use and shared) in existing neighborhoods at the block scale. This single focus can be evaluated relative to avoided GHG production and potentially deployed across multiple blocks affecting entire cities.

In addition, project team members acknowledged that a retrofit project would include preconditions and unknowns that effect both data development, and in turn, cost estimation, which is a critical decision making factor in the planning process. Upgrades and installation necessary for each house would be highly variable, as maintenance and improvements have taken place over the lifespan of each home (+/- 100 years in several cases). With this in mind, the project team is acutely aware of data availability and the need to develop protocols for data collection and standardization.

The interview results suggest that deploying the Oakland EcoBlock and scaling up the approach will be affected by factors identified in other research: specifically, the success to which the project team can secure external support, develop generalizable approaches, and create compelling narratives (Ruggiero et al. 2018). First, it is necessary to identify who should support similar projects into the future to supplement limited state dollars and build external support, including resources, policy, and funding. Second, translating specific project experience into generalizable approaches that move beyond the specific Oakland EcoBlock case (i.e., policy guides and business models) is important. Finally, it will be essential to create a powerful narrative around the Oakland EcoBlock experience as a political device to further promote additional efforts using this same approach. Narratives are also needed for community based social marketing already used by cooperatives to effectively reduce barriers to the adoption of renewable energy (Viardot 2013).

The results show that the Oakland EcoBlock project team was aware of the effects of influential project stakeholders that could be identified as working at the macro (government), intercommunity (intermediary organizations), and intracommunity (local champions) levels (Ruggerio et al. 2014). The state has defined climate goals and is providing the grant funding to undertake the study. Both the University of California, Berkeley, and the City of Oakland act as intermediary organizations, providing advice and guidance about research and political processes. The university project manager assembled academic and practice project partners, and a community member rallied neighbors to attend community meetings, each acting as local champions.

The study supports findings that determining the right scale for a community sustainability project is specifically linked to planning, modeling, simulating, and demonstrating a specific project. District scale zero net energy projects present unique opportunities for renewable energy and energy efficiency, as well as other system efficiencies and conservation gains (Polly et al. 2016). The Oakland EcoBlock showed that the systems of water and energy are both likely to make gains at the block scale, with optimization for energy possible at the scale of a single block and water possible at a scale closer to sixteen blocks. This work resulted in the identification and description of economic drivers, retrofit program principles, and block scale system design principles. The effort also allows for enhancement to modeling platforms and protocols, similar to the National Renewable Energy Laboratory's (NREL) partnership on two new district projects in Denver: The National Western Center and the Sun Valley Neighborhood (see case studies).

Although this study has described the planning process for a specific neighborhood scale residential retrofit, the narratives emerging from the interviews revealed that future research should address methods of prioritizing community outreach earlier in the research and technical planning phases and improving data collection methods for a residential retrofit dependent upon current built conditions.

CONCLUSION

This paper aims to understand a project team's process for a community sustainability project that develops and documents an optimum design for implementation to transform a neighborhood (and eventually a city) from a high energy and water dependency model to the lowest possible dependency model. It identifies the factors that allowed the project team to envision a block scale, residential retrofit project to address today's challenges of resource scarcity, greenhouse gas emissions, and enhanced resilience.

Three key considerations were identified: social, legal, and governance barriers are likely to outweigh technical limitations; cost considerations relative to technology, implementation, and scalability affect critical decision making points during a project; and despite a common understanding of benefits, a variety of disparate approaches must be used to verify and communicate benefits through implementation, measurement, and discourse. The study makes two important contributions. It documents the project team's process for the Oakland EcoBlock to unlock the transformative potential of a neighborhood scale sustainability project. It also describes key factors in decision making to understand ways in which similar efforts can be undertaken to achieve maximum energy efficiency, renewable energy production, water conservation, stormwater capture, and localized wastewater treatment to reduce use and capture flows.

Through this process, the project also developed a recommended neighborhood scale Zero Net Energy (ZNE) Retrofit Master Plan (Barr 2019) with estimated performance levels at close to ZNE at each house, 65 percent reduction in carbon dioxide production at the block scale (including transportation) and 60 to 70 percent reduction in water use. In addition, a roadmap for distributed energy resource systems; regulatory processes; alternative financing, governance, and business models; market and information transfer; and other benefits was described in the final project report.

For existing neighborhoods throughout American cities, the design and implementation plan for the Oakland EcoBlock is encouraging. Reducing the energy and water intensity of districts can address some of the most dire needs today. However, to realize transformation, teams will need to develop new legal and governance structures with robust community processes; identify and create revenue sources for demonstration projects and the associated emerging markets for technology; and continue to implement, document, and communicate the benefits of this project and other similar residential retrofit neighborhood scale sustainability projects.

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DEFINING ECOLOGICAL NICHEs FOR GREEN FACADES: A CASE STUDY IN SHENZHEN, CHINA

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ABSTRACT

Nowadays, there is an increasing public awareness of the negative impacts that accelerating urbanization has on the environment. Green facade is an ecological architecture design strategy in the intense urbanization process that can respond to the environmental challenges.

The aim of this paper is to define ecological niches for green facades in a high-density residential community through urban microclimate analysis. This study attempts to simulate the most accurate microclimates on the building facades and road pavement from two spatial scales—residential area and individual building through data organization and visualization using the software of Ladybug Tools and ENVI-met combination. The main parameters are daylight hours, wind speed, relative humidity and surface temperature of the building facade. These parameters are derived from EnergyPlus Weather Data in the hottest week of summer.

This study compares the impact on the thermal environment of various building facades in high-density living conditions. Moreover, greening of facades provides a cooling mechanism on building elevations, it can minimize the heat island effect during summer. The potential of green facades is reviewed. The method is demonstrated by a case study in Baishizhou, which is one of the communities that has the highest density in Shenzhen, China. The results of these simulations show that 1. there is a big difference between the thermal environment of different building facades in the same climate condition; 2. green facades can contribute positively to the cooling effect on buildings.

KEYWORDS

High-Density Area; Urban Microclimate; Simulation; Green Facades, Ecological Niches

INTRODUCTION

Accelerating urbanization and population growth has caused huge changes in urban environment. For example, during China's rapid urbanization in the last four decades, urban villages (chengzhongcun by Chinese) have become a phenomenal case. In these villages, buildings are called “handshake buildings” because of the high density. The overwhelming density thus created issues like no vegetation coverage, poor sanitary conditions, overcrowded population, and environmental pollution [1,2]. The existence of these environmental issues has caused changes in the microclimate environment in these villages, giving rise to the Urban Heat Island effect (UHI). The UHI is an urban area has much warmer temperature than the surrounding area due to human activities [3,4]. To date, many studies have investigated an ecological solution to mitigate UHI and cool the microclimate by introduction of vegetation, because vegetation absorbs short wave radiation, reduce solar re-radiation from hard surfaces, and cool the environment by plants shading effects, evaporation and transpiration [1].

Based on the cooling effect of vegetation, green facades and green roof can be considered as a significant technique used to adding urban greenery in the high-density urban area like urban villages in Shenzhen with limited ground area for tree-planting [5]. Green facades are covered directly or indirectly by herbaceous or creeper on the ground or in planter boxes to cover buildings with foliage, support systems are sometimes needed, which are called green vertical systems or façade greening systems [1,6]. Green roof is a roof covered with green vegetation and growing medium, also named eco-roof, roof garden and living roof [7]. With the development of green facades and green roof in the past years, they became more widely used in urban greenery. Between two green building technologies, green facades provide more green spaces and improve the urban landscape and views compared to green roofs in a high-rise building area [8]. Thus, there is a growing body of literature and application on green facades in recent decades.

The cooling effect of green facades on building surface temperature have been widely investigated by measurements method [5]. For example, Hoyano found green façade has a lower outdoor surface temperature by nearly 10 °C on the summer days in Japan [9]. Hien and Ong measured a surface temperature reduction of up to 11.6 °C in Singapore [5]. Chen revealed that the maximum reduction was 20.8 °C on outdoor surface temperature, whereas 7.7 °C on indoor surface temperature from living wall in Wuhan, China [10]. In the other research, Mazzali found a huge difference between living walls and bare walls of building surface temperatures ranging from 12°C to 20°C in Italy [11]. Yin found the cool façade surfaces with a maximum reduction of 4.67 °C, and temperature was significantly reduced at night under hot summer days in Nanjing, China [12]. Hoelscher study of three typical façade greening species showed that the cooling effects mainly depend on shading. Surface temperatures of the greened exterior walls were up to 15.5 °C lower than those of the bare walls during hot summer nights in Berlin, Germany [13]. Hence, the cooling effect experimental study for green facades have received enormous academic attention in recent decades. Their results show various in building surface temperature reduction by green facades in different climates, wall materials, regions and plant species.

While few studies have used a comprehensive modelling method. In these few studies, Susorova developed EnergyPlus energy analysis software, with which they show the temperature reduction of traditional green facade [14]. In addition, this method has been supported by a measurement in Chicago. Similarly, Dahanayake and Chow simulations have shown vertical greening reducing outdoor surface temperature of building facades by maximum of 26 °C in hot summer days in Hong Kong through a mathematical model integrated with EnergyPlus, building simulation program [15].

In general, all of the previous studies reviewed here support the hypothesis that green facades can contribute positively to the cooling effect on buildings through multiple methods. However, such studies remain narrow only focusing on individual building scale, very little was found in the literature on community scale in high density living environment. Therefore, the focus of this research is to compare the impacts of building density on the thermal environment of various building surfaces at different scales. It attempts to simulate the most accurate microclimates on two spatial scales—community and individual building by data organization and visualization. Baishizhou urban village, a high-density residential area of Shenzhen (113°510E–114°210E, 22°270N–22°390N) is used as a case study to investigate the building façades microclimate (Fig. 1.). Shenzhen is in a subtropical climate, with mild winters, hot and humid summers. The average annual temperature is 24 °C [16].



Figure 1. Distribution of Baishizhou urban village

METHODOLOGY

This study proposes a hybrid 3D visualization research method using the software combination of Rhino 7, Ladybug Tools and ENVI-met (v 4.4.6). The potential impact of building density on the microclimates has been evaluated on two scales, the community scale and individual building scale. At the community scale, this study selects two target areas located on the south side of Baishizhou. Each area is 100m x 100m. Then the simulations are run for 1 hour for both areas. The sample time is 14:00 on the 9th of August 2019. At the building scale, one random residential building is selected within the area no.1, and simulation is run for 24 hours. The main parameters are sunlight, wind speed, relative humidity and air temperature.

Software used in the study

Ladybug

In the other previous study, the associated mathematical modelling software like EnergyPlus were more widely used. However, this software is limited in the data transfer between 3D modelling simulation and design process. In this case, Rhino/Grasshopper, one of the most well-known parametric design software in the architecture design industry which can break down the limitations through visual programming language and design (CAD) application, is chosen for this study. This software provides multiple benefits for integrating design and analysis. Using the design platform to visualize environmental analysis data allows designers to create a clear link between data analysis and design [17]. In the Rhino and Grasshopper programs, Ladybug Tools is a free and open-source plug-in for Rhino/Grasshopper and Revit/Dynamo created by Mostapha (grasshopper3d.com). This plug-in is one of the most comprehensive environmental design software packages, connecting 3D Computer-Aided Design (CAD) interfaces to a complement of validated simulation engines (grasshopper3d.com). It allows users to import standard weather files (.epw) into Grasshopper [18]. Thus, Ladybug Tools is a powerful toolkit for dealing with 3D geometry and environmental simulation.

Dragonfly

For the rest of the case study calculation, wind speed, relative humidity, air temperature and outside surface temperature simulation is run in Dragonfly, a plugin of Ladybug Tools connects Ladybug and ENVI-met. This plugin is created by Antonello Di Nunzio, it enables the modelling and estimation of large-scale climatic phenomenon like urban heat island. Besides, this plugin is developed to ensure ENVI-met's functionality while to avoid the limitations of its applicability to microscale simulations and interconnection with external tool [19]. Thus, Dragonfly as a part of this study simulation methods.

In the simulation process of this study, input data for ENVI-met (V. 4.4.6) microclimatic modelling is set in Grasshopper using a collection of designated components which automatically translate different inputs to Area Input (.INX) and Simulation (.SIM) Files for each iteration. These data include the building geometrical characteristics, the Shenzhen climatic data -e.g. wind speed and direction, hourly air temperature and relative humidity - and in this case, the grid density was set to 2m. After each simulation, results are automatically uploaded to Grasshopper [20].

As a result of the establishment of the simulation methods, the following subsections discuss the parameters set up and the calculation results.

Research objects

At the community scale, this study selected two target areas located on the south side of Baishizhou with different architectural features and building coverage ratios. Area 1 has 63 residential buildings, 60.86% building coverage ratio, high-rise residential buildings and no planting areas. Area 2 has 47.59% building coverage ratio, high-rise buildings with different programs (serving commercial buildings), and no planting areas (Fig. 2.).

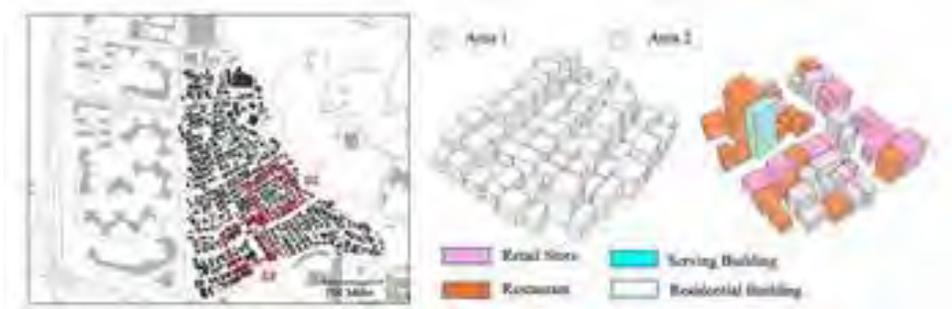


Figure 2. The two areas location and building function

At the building scale, one random residential building is selected within the area (Fig. 3.). Because this building presents a huge difference between building surfaces temperature and daylight duration from community scale simulation results. This building height is 26m, one layer area is 168m².Simulation is run for 24 hours.

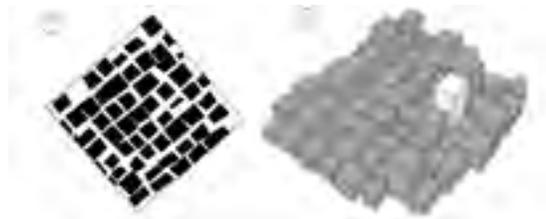


Figure 3. Individual building selected

Parameters set up

Then the simulations are run for 1 hour for both areas at community scale. The sample time is 14:00 on the 9th of August 2019. The simulation data collection is shown in table 1.

Table 1: The Areas Scale Simulation Sets

| | |
|--|---|
| 14:00.09.08.2019 at 3m simulation data collection | Wind Speed measured in 3m height: 3.5 m/s |
| Simulation Input Data | Wind direction: 239° |
| Simulation Model Size(m): 120x120x40 | Initial Temperature of atmosphere: 34.3°C |
| Mode Area (Number of Grids) xyz-Grids: 80x80x20 | Min Temperature (simulation date): 28.4°C,0:00h;3:00h,8:00h |
| Size of grid cell(meters) x,y,z: 2x2x2 | Max Temperature (simulation date): 35.9°C, 14:00h |
| Geographic Location (Latitude, Longitude): 22.5,114.10 | Relative Humidity in 3m height (%):60.27% |
| Nesting grid: without | Min humidity (simulation date): 58.07%,15:00h |
| Method of vertical grid generation: Equidistant | Max humidity (simulation date): 94.55%,2:00h |
| Reference time zone: GMT+8 | Element types of build environment |
| Main model parameters | Element type: Albedo |
| Simulation Model Date: 09-Aug-19 | [0100B1] BRICK WALL (AERATED):0.3 |
| Start & Duration of Simulation: 13:00,1h | [0000KK] BRICK ROAD (RED STONES):0.3 |

At the building scale, simulation is run for 24 hours. The simulation data collection is shown in table 2.

Table 2 : The Individual Building Scale Simulation Sets

| | |
|---|---|
| 09.08.2019 at 3m simulation data collection Simulation Input Data Simulation Model Size(m): 120x120x40 Mode Area (Number of Grids) xyz-Grids: 30x30x20 Size of grid cell(meters) x,y,z: 2x2x2 Geographic Location (Latitude, Longitude): 22.5,114.10 Nesting grid: without Method of vertical grid generation: Equidistant Reference time zone: GMT+8 Main model parameters Simulation Model Date: 09-Aug-19 Start & Duration of Simulation: 00:00,24h | Wind Speed measured in 3m height: 3.3 m/s Wind direction: 188° Initial Temperature of atmosphere: 28.4°C Min Temperature (simulation date): 28.4°C,0:00h;3:00h,8:00h Max Temperature (simulation date): 35.9°C, 14:00h Relative Humidity in 3m height (%):77.77% Min humidity (simulation date): 58.07%,15:00h Max humidity (simulation date): 94.55%,2:00h Element types of build environment Element type: Albedo [0100B1] BRICK WALL (AERATED):0.3 [0000KK] BRICK ROAD (RED STONES):0.3 |
|---|---|

RESULTS AND DISCUSSION

The simulation outputs of two spatial scales are presented in table 3 and table 4. This outputs, in the form of outdoor microclimate maps concerning wind speed, humidity, air temperature and outside surface temperature, are extracted and elaborated on by ENVI-met. Daylight hours are calculated by Ladybug. The simulation results at the two scales are discussed below.

Microclimate simulations at community scale

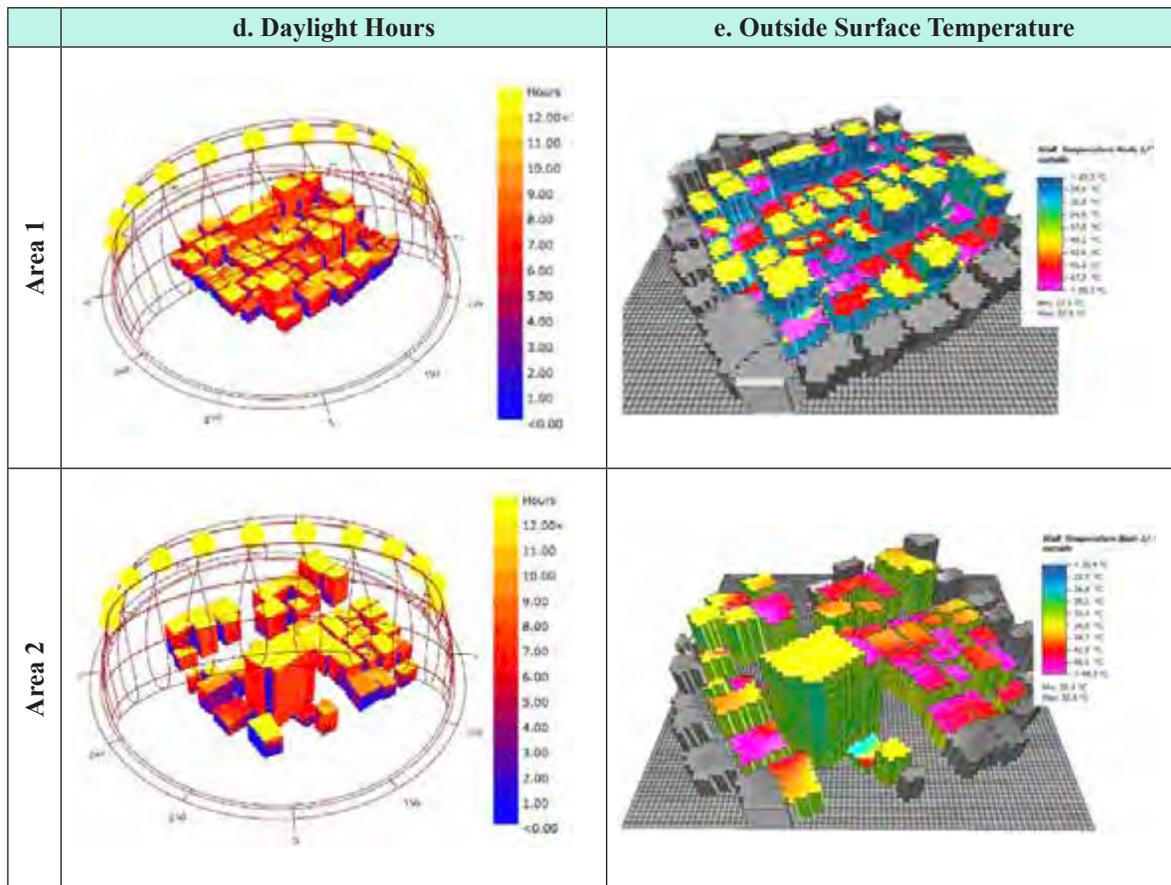
Table 3 displays a comparison of the microclimate maps generated for two areas, on the 9th of August, at 14:00. Graph a showed that the wind speed variation in the two areas. It can be found from the wind speed simulation results that, the distance between the buildings in the area1 is narrow, and it is difficult for the air to pass through smoothly. Furthermore, area1 is part of an enclosed residential block, which would decrease the air speed in the area. There are two streets acrossing though area 2, reducing the density of buildings in the entire zone. Thus, the wind speed in the area1 is close zero, while the wind speed in the area 2 ranges from 0m/s to 3.8 m/s, which has significantly decreased from streets to building facades. Graph b indicates the same relative humidity in both areas in the same climate condition. The lowest relative humidity is found in the vicinity of buildings in both areas with a minimum of 19.6%. Graph c shows that a huge difference exists in the air temperature of the two areas at ground level (1 m). The highest temperature is found in the vicinity of the buildings with a maximum of 36 °C, higher than the average temperature of about 15°C in the two areas. When coupled with the graphic information, the findings demonstrate that microclimate maps were closely related to the building density in the two areas. Hence, high building density results in lower wind speed, higher surface temperature, and lower humidity.

Table 3: Microclimate Map Between Area1 and Area2

| | a. Wind speed | b. Relative Humidity | c. Air Temperature |
|--------|---|--|--|
| Area 1 | <p>Wind speed legend: 0.0 m/s to 3.0 m/s. Min: 0.0 m/s, Max: 3.0 m/s.</p> | <p>Relative Humidity legend: 19.6% to 50.0%. Min: 19.6%, Max: 50.0%.</p> | <p>Potential Air Temperature legend: 28.4°C to 35.9°C. Min: 28.4°C, Max: 35.9°C.</p> |
| Area 2 | <p>Wind speed legend: 0.0 m/s to 3.8 m/s. Min: 0.0 m/s, Max: 3.8 m/s.</p> | <p>Relative Humidity legend: 19.6% to 50.0%. Min: 19.6%, Max: 50.0%.</p> | <p>Potential Air Temperature legend: 28.4°C to 36°C. Min: 28.4°C, Max: 36°C.</p> |

Table 4 displays a comparison of the daylight hours and temperature of building surface recorded for two areas, on the 9th of August, at 14:00. Graph d revealed that the building surfaces in the area 2 is exposed to more direct sunlight than those in the area 1 since the building density in the area 2 is lower than area1. From graph e, it can be concluded that the temperature of the building roofs is significantly higher than that of building façades and ground temperature. Thus, the two area simulates showed that the maximum temperature difference between the building roof and building façades is approximately 25°C. Thus, the density of buildings has a direct impact on the building outside surface temperature and daylight duration on building surface. High building density results in lower daylight duration on building façades, and higher building surface temperature.

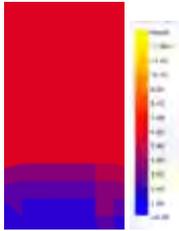
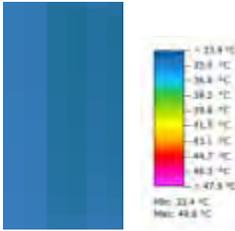
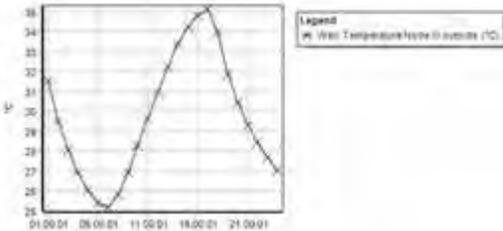
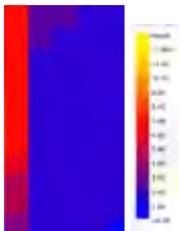
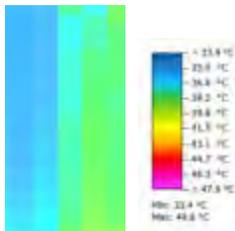
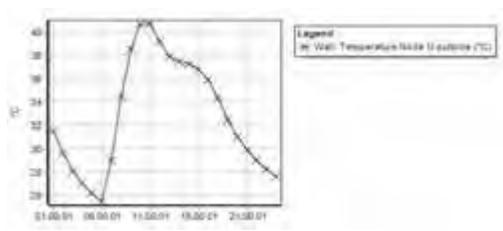
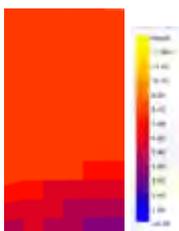
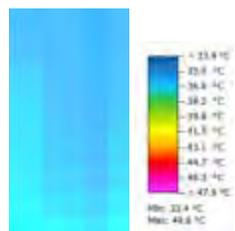
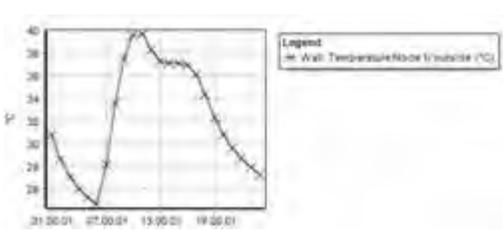
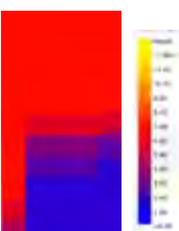
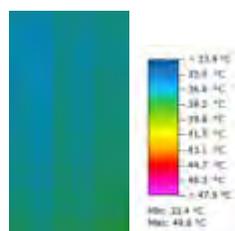
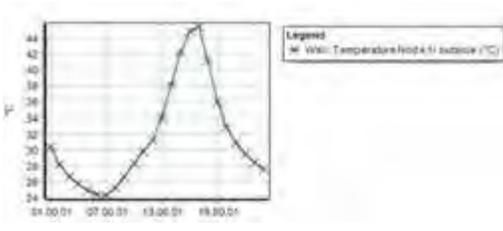
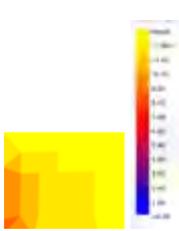
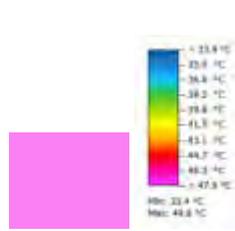
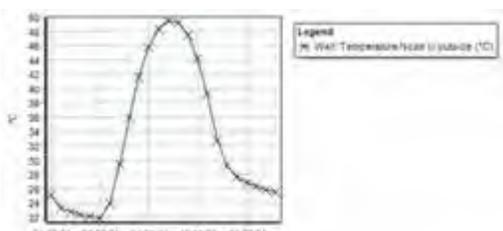
Table 4: Daylight Hours and Outside Surface Temperature Modelling Between Area1 and Area2



Microclimate simulation at individual building scale

At the individual building scale, this study mainly focused on how the building density affected daylight hours and temperature of building surface. Table 5 lists the daily change of building surface temperature and daylight duration, and the difference on building surface temperature at 14:00 facing different orientations. The individual building simulation results of 24 hours are as follows: 1. the building roof with the longest daylight duration and exposure to direct sunlight as has significantly higher than its building façades. To illustrate, at 14:00, the roof temperature peaked at 49.5°C, while the facade temperatures were stay between 33.4°C and 38.2°C. 2. building density greatly influences daylight duration on building façades. Table 5 showed that 20% of the north side of the building had daylight for less than two hours, while 80% of it had 3-5 hours. 82% of the east side of building had less than 2 hours of daylight, while 18% had 4-6 hours. On the south façade, 82% of daylight hours lies between 5 and 7 hours, while 18% have between 3 and 4 hours. In addition, 39% of daylight hours on the west façade lies between 2 and 4 hours, while 61% between 4 and 6 hours.

Table 5: Daylight Hours and Outside Façade Temperature in Individual Building

| | Daylight Hours Simulation (hours) | Building surface Temperature (°C) at 14:00pm | Wall Temperature (°C) |
|----------------------|---|---|--|
| Facade1 North |  |  |  |
| Facade2 East |  |  |  |
| Facade3 South |  |  |  |
| Facade2 West |  |  |  |
| Top |  |  |  |

CONCLUSION AND FUTURE WORK

This study proposed that green facade is an ecological strategy to improve the thermal environment of high-density urban agglomerations through the previous multiple methods reviewed. Besides, we studied as the difference between the thermal environment of different building surfaces in the same climate condition. In the process of research method study, we found the limitations of mathematical modelling software like EnergyPlus used to 3D modelling simulation and design process. Thus, we develop a “hybrid” method for microclimate simulation to evaluate microclimate on multiple scales through Grasshopper software. This method was used to simulate the microclimate in a high-density residential area, known as urban villages in Shenzhen. The study results showed that building surface temperature affected by two factors, one is affected by the local climate conditions in summer, the other is affected by building density. The study has also shown that the building roof temperature reaches the highest in summer, which was higher than building facades temperature. Therefore, rightly placed green façade and green roof should be innovatively combined and applied in urban design to reduce the heat island effect especially in tropical climates. The future study will continue to test out the most suitable vertical greening systems and plant species to mitigate environmental damages and reduce energy consumptions in the urban villages of Shenzhen.

ACKNOWLEDGMENT

The first author is very thankful to the China Scholarship Council of Chinese government for the funding support provided to conduct this research.

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GREEN INFRASTRUCTURE MEASURES TO MITIGATE THE URBAN HEAT ISLAND OF IBEJU LEKKI, LAGOS, NIGERIA

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ABSTRACT

Urban heat island (UHI) effects have received serious attention globally due to their detrimental impacts on human and environmental health. These effects are noticeable in cities where natural land cover have been replaced with impervious surfaces, buildings and urban infrastructure, thereby increasing the micro-climate changes due to temperature increase. This paper seeks to analyse the UHI effect in Ibeju Lekki, Lagos, Nigeria with the view to recommending green infrastructure to mitigate its impact in the light of rapid urbanization rates. The study assessed and analyzed the UHI factors of the case study using multi-temporal Landsat imageries to generate land surface temperature (LST) and land use/land cover of the study area for 1984, 2000, 2010 and 2020. Built-up areas have significantly increased from 4.1% in 1984 to 20.9% in 2020 thereby bringing about a significant loss of green land cover. Variations and increased temperature from the thermal reflection of each land use and land cover in Ibeju Lekki, Lagos are also noticeable. This affirms that continuous conversion of natural land cover to other uses contributes significantly to the overall surface temperature in Ibeju Lekki. This study, therefore, recommends the provision of green infrastructures such as urban tree canopy, parks, open spaces and ecological landscaping to mitigate the surface temperature of Ibeju Lekki, thus alleviating health problems and hazards that often accompany temperature increases.

KEYWORDS

Green infrastructure, land surface temperature, mitigation, urban heat island, urbanization

INTRODUCTION

Energy and climate are highly associated with the built environment, which is comprised of building collections and the physical results of various economic, social and environmental processes [1]. Effects of Urban micro-climate change is evident in major cities through urban heat islands, due to urban expansion, increase in pollution, and the development of major industrial activities [2]. Globally, urban systems have undergone rapid development due to the transition in population distribution. About 55% of the global population reside in urban areas [3] and this is expected to increase to 68% by 2050. This means that cities will not only experience increased temperature from global warming but also due to Urban Heat Island (UHI) effects [4]. Urban Heat Island (UHI) is the characteristic increase in the temperature of cities compared with their surroundings and a notable climatic response to ecological disruptions caused by urban development [5]. The changes in temperature, including extreme weather events caused by urban heat island phenomenon increase heat-related diseases and alter environmental conditions by aggravating the incidence of climate change in urban areas [6]. Human activities as a result of urbanization and industrial revolution have substantially added to the amount of heat-trapping greenhouse gases in the atmosphere in most cities. This phenomenon does not only accelerate urban temperature and air pollution but also significantly increase energy consumption and reduce the quality of life [7].

Anthropogenic global warming is aggravating UHI effects due to increased average temperatures with decrease in precipitation [8]. The summer heat load due to climate change most likely will result in the increase of heat waves in many areas with higher intensities and longer duration of heat. For instance, Lagos and Shanghai are likely to experience heat stress by 2050 if the global temperature rises by 1.5°C exposing more than 350 million people to heat related diseases such as malaria and dengue fever [9]. Heat waves is one of the major risk factors of UHI as they can affect human health causing exhaustion, dehydration, circulatory disorders, and potentially death [10]. It endangers mostly vulnerable individuals, such as elderly people, the very young, those with social or physical impairments or those unable to afford mitigation measures such as air conditioning [11]. Radhi, Fikry and Sharples [12] mentioned that urban thermal behaviour and patterns are mainly distorted by large scale urban construction, loss of wetlands and water bodies that characterize most urban space, making land use and land cover changes a prominent feature of urbanization [13]. Rapid and uncontrolled urban expansion, the usage of paved surfaces, reduction of green areas, heat emission by vehicles and industrial activities contributes significantly to the rise in temperature in urban areas. The swift changes and variation in urban climate through anthropogenic warming are now of global concern [4]. Traffic congestion, informal settlements, urban sprawl, environmental pollution and overexploitation of water resources contributes to the alteration of the microclimate of most cities [14]. The raise in urban temperature is experienced when there is a significant reduction in cities' green infrastructure to make way to developments such as industrial buildings, warehouses, airport runways without alternative measures to restore them [15].

Green infrastructure (GI) is a mix of natural approaches and processes needed to achieve varieties of environmental and sustainability goal [16]. It often comprises of urban trees and forests, parks and open green spaces, street trees, sustainable urban drainage systems (SUDs) and building integrated vegetation [17]. Urban trees have the potential to dampen the UHI and decrease near-surface temperatures through direct shading and evaporative cooling [18]. Thus, GI offer significant benefits in reducing building air-conditioning demand, improving urban air quality by reducing smog [19]. A study by Armson, Rahman, & Ennos revealed that dense and tall trees canyon reduced surface and radiant temperature by 12°C and 4°C in two streets of Greater Manchester, United Kingdom [20]. Quantities of trees planted can have a significant effect on temperature level as portrayed by [21] Skelhorn, Lindley, & Levermore that a 5% increase in matured deciduous trees can reduce temperature level by about 10°C. The effectiveness of green infrastructure in reducing urban heat islands has been proven through measurements (field measurements, scale models, and thermal remote sensing), and computer simulation [22] [23]. Studies have shown that combination of different green elements in cities helps achieve best mitigation or prevention against microclimate and thermal discomfort as well as reduce energy demand for cooling [24]. Adedeji & Fadairo (2015) and Yiannakou & Salata (2017) asserted that green infrastructure is an ecosystem-based approach and one of the best planning tools for adapting to and mitigating urban climate change [25] [26]. GI is therefore a multifunctional network; the design and management of this network can contribute to the sustainability of communities and enhance the local character of urban areas [27].

The vulnerability of cities to heat island effects due to urbanisation and associated ecological degradation have triggered extensive research in recent times. The effects of Urban Heat Island are gradually becoming evident in Ibeju Lekki due to serious land use land cover changes in the area consequent on industrialization, infrastructure and housing provision. Although, the variations in Land surface temperature as a result of deforestation have been well explored in other parts of Lagos State, none of them have taken cognizance of the vulnerability of Ibeju Lekki to UHI effects. For instance, Ojeh, Balogun, & Okhimamhe [28]

estimated UHI magnitude in Lagos by investigating the urban-rural temperature difference and effects of solar radiation and wind speed. This study discovered that maximum nocturnal UHI magnitudes in Lagos can exceed 7°C during the dry season, while during the rainy season, wet soils in the rural environment supersede regional wind speed as the dominant control over UHI magnitude. Also, [29], assessed the spatial extent of urban growth and its implication on UHI effects in Lagos State and findings revealed that there have been changes in the land cover which had increased the land surface temperature between 2002 and 2013 [29]. All these studies were necessary to understand the extent to which urbanisation has contributed to the heat island effects in Lagos state. Despite the extent of details in some of these studies, none of them have looked into Ibeju-Lekki specifically being a coastal community and an area on increasing physical development. This study assessed the vulnerability of Ibeju-Lekki to UHI effects by analyzing the impacts of land use & land cover changes on UHI phenomenon in the study area and suggest how green infrastructure can be an effective means to reduce UHI.

MATERIALS AND METHODS

Research Locale

The study area is located in Ibeju Lekki local government area, Lagos state, Nigeria. Ibeju Lekki is approximately 75 kilometres long and about 20 kilometres wide [15], with a land area of about 646 kilometres square which amounts to about one quarter of the total land mass of Lagos State [5]. It represents one of the fastest growing peri-urban settlements in Lagos with respect to population influx, residential and industrial development and is expected to be a central hub for business and manufacturing activities due to the ongoing developmental activities in the area [21]. Being part of the Ibeju Lekki Local Government Area in Lagos State, the area is characterized by the tropical swamp forest and experience rainfall throughout the year due to its proximity to the Atlantic Ocean [23]. Fig. 1. shows the location of the study area

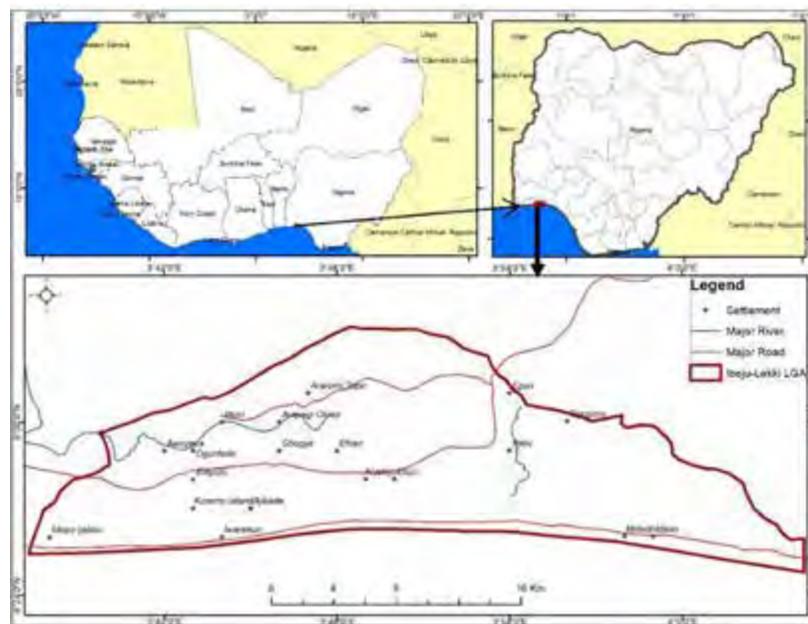


Figure 1: Geographical location of the Study Area

Data sources and Research Procedure

Data were obtained from secondary sources, specifically, Landsat imageries were obtained from USGS to assess changes in land cover and land surface temperature of the study area. The analysis was done for 20 years from 2000 to 2020 using 1984 as the base year. Geometrically corrected Landsat satellite images were acquired from United States Geological Survey Portal using appropriate search criteria. The Landsat satellite images (path 191, row 055; path 191, row 056) include Enhanced Thematic Mapper Plus (ETM+), Thematic Mapper (TM), and Operational Land Imager (OLI) (see Table I). The imageries were subjected

to cleaning to remove excess cloud cover using the approach adopted by [4]. For proper comparison of land cover change and estimation of variations in land surface temperature that had occurred between 1984 to 2020, all the images were acquired in January, as this time, the cloud cover in the study area was less making changes in both land cover and surface temperature visible.

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The bands of each Landsat datasets were stacked together into a single raster and symbolized appropriately to make the various land cover in the study area visible. Training samples were generated from the stacked raster using the image classification tool on Arc Map 10.7. The training samples were then subjected to supervised classification method using the Maximum Likelihood (ML) classification function. The ML gives a better performance than other known parametric classifiers and it incorporates the variance–covariance within class and normal distribution [30]. For the classification, built-up areas, forest/vegetated areas, bare ground and water bodies the land use categories that were used

Using Google Earth historical imagery as reference, ground verification points were established to compare features interpreted on the historical imageries and their corresponding output in the land use/land cover classification. This process is appropriate in detecting the correctly classified pixels, pixels assigned to classes to which they do not belong (commission errors) and pixels assigned to more than one class at the same time (omission errors) [31]. The area of the land cover classes was calculated and expressed in hectares and percentages using Microsoft Excel. This process was repeated for 2000, 2010 and 2020 to identify the trend of the change using 1984 as the base year.

Similarly, the land surface temperature (LST) of the study area was estimated from 2002 to 2020 using a remote sensing technique. The Landsat thermal Band 6 (EM & ETM+) and Band 10 and 11 (TIRS) were used for the retrieval of the LST in the study area following the single channel method as applied by [32]. Retrieval of the land surface temperature of the study area was achieved in four main parts. This include conversion of the digital number to spectral radiance, estimating the top of atmosphere brightness temperature, calculating the land surface emissivity and finally estimating the land surface temperature.

For all satellite images, the calibration was achieved by converting raw digital numbers (DN) into at-sensor spectral radiance [33] using equation 1 as obtained from [33]. The procedure is highlighted using Fig. 2.

$$L\lambda = ((L_{MAX\lambda} - L_{MIN\lambda}) / (QCAL_{MAX} - QCAL_{MIN})) * (QCAL - QCAL_{MIN}) + L_{MIN\lambda} \tag{Eq. 1}$$

Where:

QCAL = quantized calibrated pixel value in DN,

LMIN = the spectral radiance scaled to QCALMIN (3.2) watts/(m²*ster*µm)

LMAX = the spectral radiance scaled to QCALMAX (12.650) watts/(m²*ster*µm)

QCALMIN = the minimum quantized calibrated pixel value in DN (1.0)

QCALMAX = the maximum quantized calibrated pixel value in DN

The top of atmosphere (TOA) brightness temperature was calculated in degree Celsius using equation 2.

$$T_b = K2 / \ln(K1 / (L\lambda + 1)) \tag{Eq. 2}$$

Where:

Lλ = TOA Spectral radiance (Watts/(m² *srad *µm))

K1 = Thermal conversion constant for the band

K2 = Thermal conversion constant for the band

The Land Surface Emissivity (LSE) model provides the best performance on all LST retrieval methods. Since LSE is one of the most important factors influencing the LST estimation reliability, the effects of vegetation proportion were investigated by computing the Normalized Difference Vegetation Index (NDVI) using the formula in equation 3.

$$NDVI = (NIR - R) / (NIR + R) \tag{Eq. 3}$$

Where:

NIR = the near infrared

R = the red reflectance

The proportion of vegetation was computed using the formula in equation 4 [37].

$$P_v = ((NDVI - NDVI_{MIN}) / (NDVI_{MAX} - NDVI_{MIN}))^2 \tag{Eq. 4}$$

Where:

PV = proportion of vegetation

NDVI = Normalized Difference Vegetation Index

NDVI_{MAX} = Normalized Difference Vegetation Index Maximum

NDVI_{MIN} = Normalized Difference Vegetation Index Minimum

The Spectral emissivity was then determined using the following equation [37]

$$e = 0.004P_v + 0.986 \tag{Eq. 5}$$

The brightness temperature was subsequently converted to LST using Eq. (6)

$$LST = (T_b / 1 + (\lambda * TB / \rho) * \ln(e)) \tag{Eq. 6}$$

Where:

T_b = Top of Atmosphere Brightness Temperature (°C)

λ = wavelength of the emitted radiance (11.45 μm)

e = Land Surface Emissivity

ρ = 1.438 × 10⁻² Mk

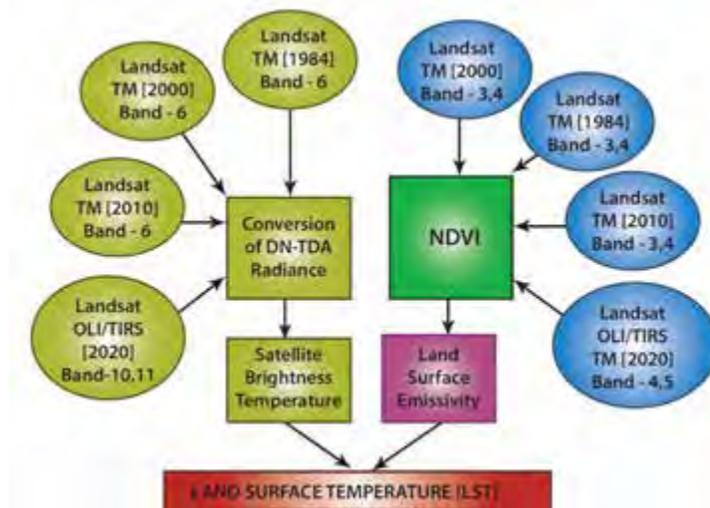


Figure 2: Method followed for LST Analysis

Following the above stated methodology, the land surface temperature is derived from the spectral radiance by first converting the digital numbers (DN) into spectral radiance L. This was further converted to brightness temperature BT in Kelvin. The land surface temperature (LST) in Kelvin was then converted to Celsius using $LST (^{\circ}C) = LST - 273.15$. For year 2020, the Landsat (OLI) was used alongside the NDVI outputs to obtain the 2020 Land Surface Temperature which had a maximum of 33.2°C and a minimum of 21.2°C.

RESULTS AND DISCUSSION

Land Use and Land Cover Changes in the Study Area.

Four major land cover were discovered in the study area which include built-up areas, water bodies, forest/vegetation and bare surfaces. The final classified maps were generated by showing the different land cover types and the spatial distribution of each class in Ibeju Lekki Area for 1984, 2000, 2010 and 2020 (Figure 3 and Table 1). Prior 1984, the study area was majorly dominated by forest, bare surfaces and water bodies. In 1984, the dominant land cover was forest/vegetation (55.5%), followed by bare surfaces (35.1%), water bodies (5.2%), built-up areas were the least with about 4.1% of the total study area. Built-up area and forest/vegetation witnessed a slight increase to 5.5% and 57.8% respectively in 2000, while bare surfaces and water bodies decreased slightly in the same period. By 2010, built-up area was the only land cover whose percentage coverage have increased considerably to about 14%, others were seen to have dropped substantially in this period. Following previous trends, built-up areas witnessed a significant increase reaching 20.9%, forest/vegetation and bare surfaces decreased to 48.6% and 26.5% respectively in 2020. Water bodies was noticed to have slightly increased during this period which could be attributed to increase in artificial ponds and lakes in the area.

Table I shows areas (hectares) and percentages of each land cover classes that were identified over the period of this study. Figure 3 shows the land cover changes in the study area. Prior 1984, the study area was majorly dominated by forest, bare surfaces and water bodies. In 1984, the dominant land cover was forest/vegetation (55.5%), followed by bare surfaces (35.1%), water bodies (5.2%), built-up areas were the least with about 4.1% of the total study area. Built-up area and forest/vegetation witnessed a slight increase to 5.5% and 57.8% respectively in 2000, while bare surfaces and water bodies decreased slightly in the same period. By 2010, built-up area was the only land cover whose percentage coverage have increased considerably to about 14%, others were seen to have dropped substantially in this period. Built-up areas witnessed a significant increase reaching 20.9%, forest/vegetation and bare surfaces decreased to 48.6% and 26.5% respectively in 2020. This is due to the massive construction activities going on in Ibeju-Lekki. Many of the vegetations have been sand-filled and converted to other uses such as building constructions, commercial centres and free-trade zones, industries, oil exploration and refinery activities. Water bodies was noticed to have slightly increased during this period which could be attributed to increase in artificial ponds and lakes in the area.

Table I: Land cover analysis for 1984-2020

| Land Cover | 1984 | | 2000 | | 2010 | | 2020 | |
|----------------|-----------|---------|------------|---------|-----------|---------|-----------|---------|
| | Area (Ha) | Percent | Area (Ha.) | Percent | Area (Ha) | Percent | Area (Ha) | Percent |
| Built-up Areas | 1732.0 | 4.1 | 2326.4 | 5.5 | 5851.4 | 13.9 | 8781.5 | 20.9 |
| Bare Surfaces | 14767.8 | 35.1 | 13665.4 | 32.5 | 12738.3 | 30.3 | 11119.8 | 26.5 |
| Vegetation | 23338.2 | 55.5 | 24302.6 | 57.8 | 21883.7 | 52.1 | 20398.8 | 48.6 |
| Water Bodies | 2176.0 | 5.2 | 1719.6 | 4.1 | 1540.5 | 3.7 | 1714.0 | 4.1 |
| Total | 42014.0 | 100.0 | 42014.0 | 100.0 | 42014.0 | 100.0 | 42014.0 | 100.0 |

Source: Authors' Analysis, 2021

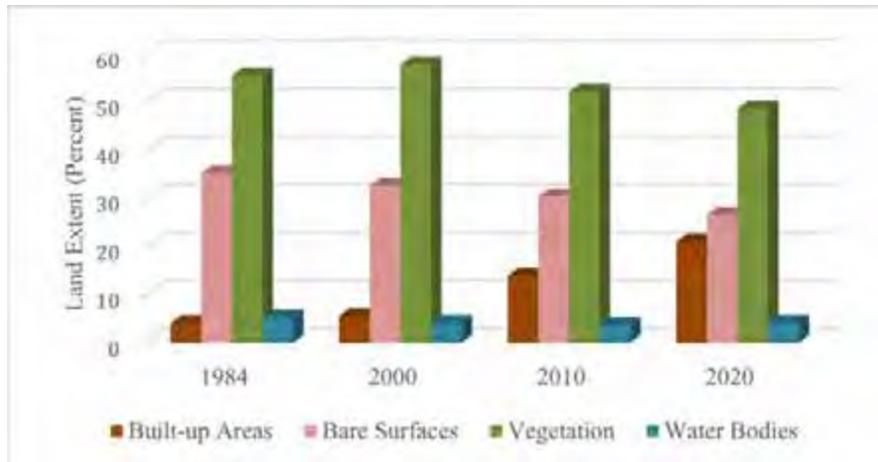


Figure 3: Land cover changes in the study area from 1984 to 2020

Furthermore, forest/vegetation, bare surfaces and water bodies decreased by 12.43%, 24.50% and 21.15% respectively between 1984 and 2020. Finally, for the entire study period from 1984 to 2020, the built-up areas increased by 409.75% (11.38% per year). Forest/vegetation substantially decreased by 12.43% (0.34% annually) while bare surfaces and water bodies decreased at the rate of 0.68% and 0.57% per year respectively. The annual rate of changes in forest/vegetation, bare surfaces and water bodies was seen to be less than 1%, while built-up areas experienced about 11% raise annually. See Fig. 4. The changes noticed are attributed to the influx of various physical developmental activities such as oil refinery, oil blending plant, beverage industries and residential estates, recreational facilities in the study area between 2000 and 2020.

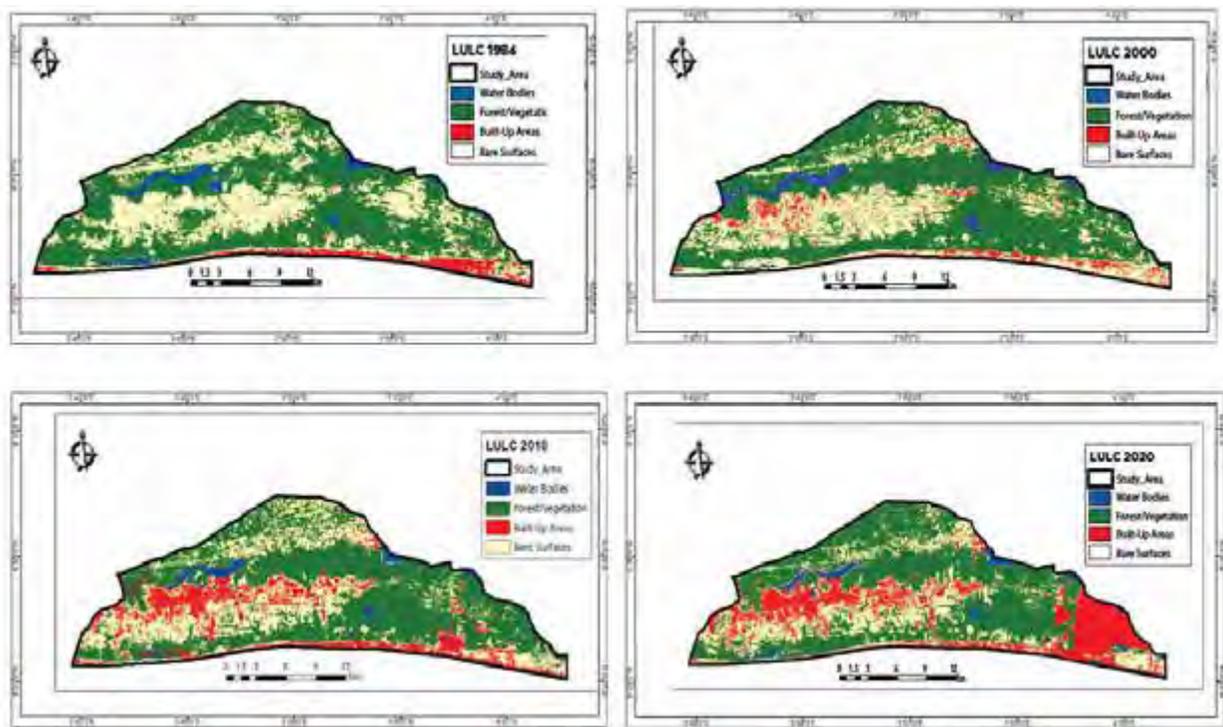


Figure 4: Land cover changes in Ibeju Lekki area between 1984 and 2020

In Ibeju Lekki area, land cover experienced a substantial change over the period of 36 years. The bare surfaces in the study area that were identified in 1984 were seen to have been physically developed especially at the central and eastern part of the study area by 2020 to meet the growing development for housing and industries. Forest/vegetation and water bodies including relevant biodiversity were also being affected by these changes. Several industries have been developed in the study area in the past two decades most especially oil refinery, free trade zones, ports, oil blending facilities etc. Thus, economic prosperity could be said to be a major force driving the changes in the area. Physical expansion of the Ibeju Lekki area was not equally propagated in all directions. The centre of the study area (e.g., Awoyaya, Efira) experienced substantial urban growth between 1984 and 2010 while development was evident in the eastern part between 2010 and 2020. Although lowland, bare soil, vegetation and water body contributed to a net change of built-up area, the contribution of built-up area to other land cover was negligible.

Spatio-Temporal Model of Land Surface Temperature

Results from the surface thermal property of the study area over the periods considered in this study shows the minimum and maximum temperature from the satellite imageries with surface temperature maps. The highest land surface temperature recorded as at year 1984 was 29.6°C while the lowest temperature was 20.2°C. The minimum temperature increased gradually between 1984 and 2000 to 20.8°C. This highest temperature significantly increased from 29.6°C to 30.4°C between 1984 and 2000. This signifies an annual increase of the minimum temperature by 0.037°C and maximum temperature by 0.05°C between 1984 and 2000. By 2010, the minimum and maximum temperature increased to 22.7°C and 32.6°C respectively. The minimum temperature dropped slightly in 2020 (21.2°C) but the maximum temperature increased to 33.2°C. Average temperatures show that there has been an increase in temperature by 2.3°C between 1984 and 2020 in Ibeju-Lekki. The trends of spatial characteristics of LST as highlighted with Fig. 5 and 6 shows that the study area experiences a steady increase in temperature between 1984 and 2020.

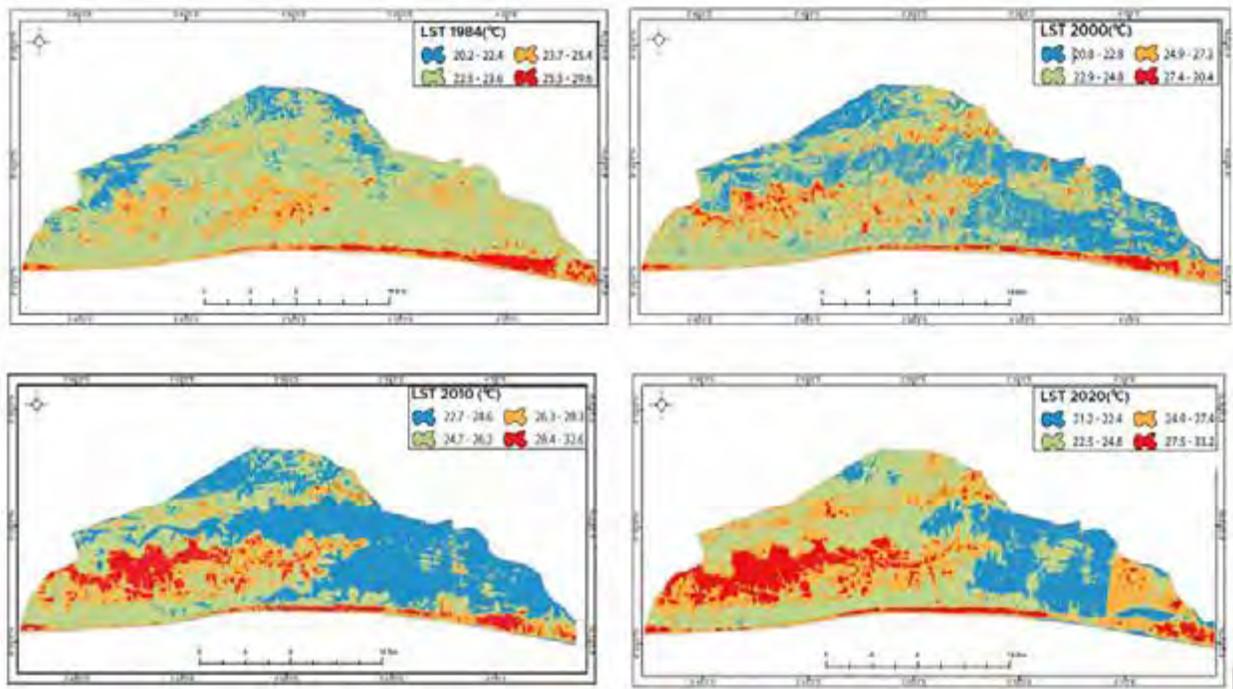


Figure 5: Land Surface Temperature for Ibeju Lekki area between 1984 and 2020

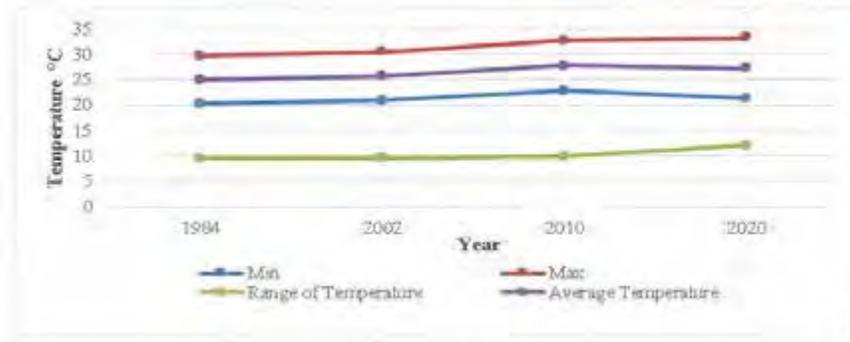


Figure 6: Trends of LST between 1984 and 2020

The Normalized Difference Vegetation Index (NDVI) as shown in Fig. 7 also indicates that great amount of vegetation has been converted to other uses. This resulted from the conversion of surface water bodies and urban green areas and vegetation covers to urban land use for physical developments through land clearing and reclamation activities in Ibeju-Lekki. The major culprit apart from residential, is the Dangote refinery, which is an integrated refinery and petrochemical project that is expected to be Africa’s biggest oil refinery upon completion by 2022. The Dangote refinery is being developed on 2,635 hectares developed on the Lekki Free-Trade Zone. The Lekki Free-Trade Zone is meant for commercial activities. Likewise, the Lagos Smart City has one of its sites on Ibeju-Lekki. Coupled with other anthropogenic activities, Ibeju-Lekki has witnessed vegetation and wetland degradation on a large scale thereby increasing impervious surfaces leading to temperature increase in the region. The surface thermal property of the study area shows that there is a general trend of increasing surface temperature in the study area over the experimented years.

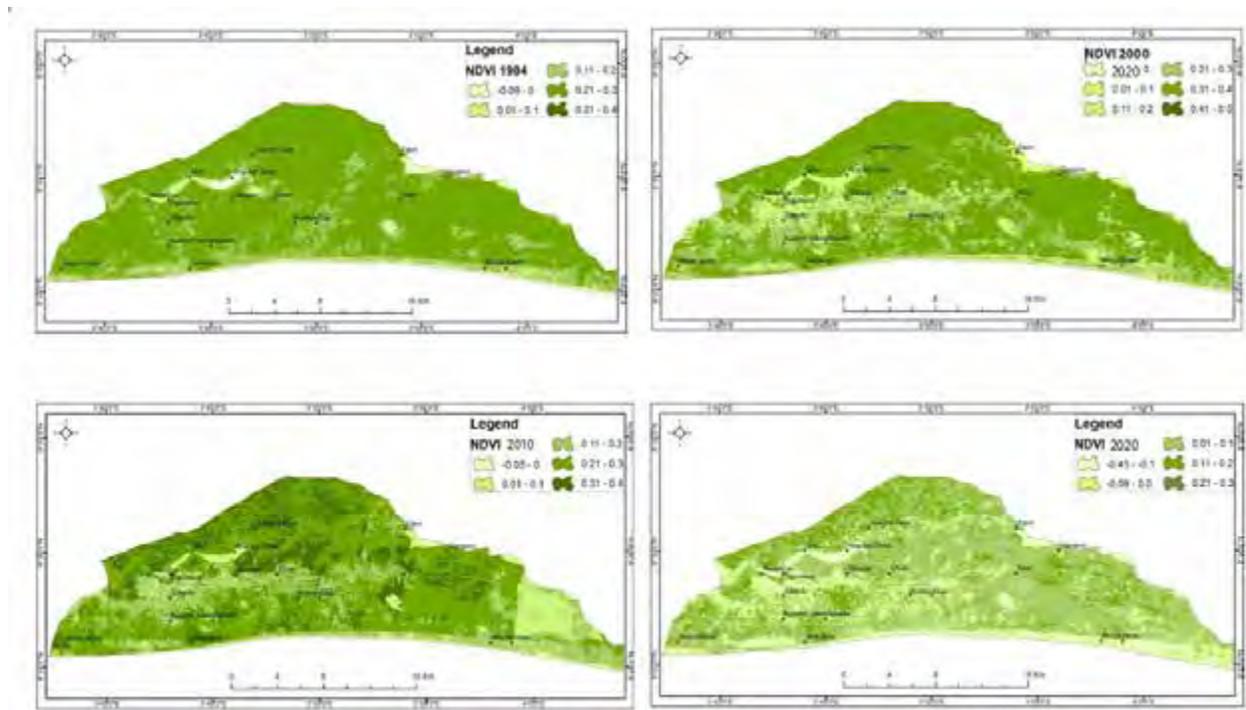


Figure 7 Normalized Difference Vegetation Index of Ibeju-Lekki between 1984 and 2020

Urban Heat Island Effects

The Urban Heat Island (UHI) can also be justified by using Inter-zone temperature difference (TLCZ X–Y) to quantify heat island magnitude. The UHI for Ibeju-Lekki metropolis in this study was thus;

$$UHI = 27.8 - 23.1 = 4.7^{\circ}\text{C}$$

Green Infrastructure Measures to Mitigate UHI in Ibeju-Lekki

This study has revealed that Ibeju Lekki has witnessed significant increase in UHI effects over the years due to urbanization and anthropogenic activities such as deforestation for construction purposes, encroachment on waterways and drainage systems, and land reclamation of potential wetlands within the study area. To mitigate this effect, there is a need to fully integrate Green Infrastructure (GI) as a measure to reduce UHI and restore healthy environment in Ibeju Lekki. GI has been suggested as a remedy for mitigating impact of impermeable urban infrastructure materials causing UHI effects such as concrete by including permeable paths, bio-swales, street planting, green roofs, green walls, rejuvenated wetlands, urban forests, parklands and other vegetative systems into the urban fabrics [34]. Urban Planners are meant to be at the fore-front of designing green infrastructure to mitigate UHI effects. If strategically designed and planned, GI can deliver multiple benefits for human wellbeing. In cities such as Birmingham, Manchester and London, GI plans to address UHI are being produced [35]. Indeed, the England's National Policy Framework requires that Local Plans should take account of climate change and GI should be planned as climate adaptation and UHI measures. This should be emulated in Ibeju-Lekki. Likewise, there should be a framework and master plan to develop ecological and compact cities needed for maintaining ecosystem services and biodiversity. To avoid further UHI experience in Ibeju Lekki, the Urban Planning Department needs to incorporate GI in planning activities in the study area. This include green roofs into the urban built-space, because the trees and plants that are critical components of these technologies are able to remove common air pollutants like nitrogen dioxide, ozone, sulfur dioxide, and some particulate matter. This also include the implementation of trees planting along the street, albedo provision in building and neighborhood designs, construction and expansion of Urban Drainage Systems. GI facilitates through urban green space and vegetation will reduce energy demands especially for air conditioning energy. Vegetation and green space can have a positive impact on human health [36]. Typical components and interfaces of GI that can be incorporated into city planning in Ibeju- Lekki should include green roofs, vertical greening hardscape, pervious pavement landscape, bioretention measures, rain gardens water, rainwater harvesting and gray water harvesting, rejuvenated wetlands, urban forests, parklands and other vegetative systems. Overall, city managers should recognize the importance of the natural environment in decisions about land-use planning and emphasizing the life support function provided by a network natural ecosystem to achieving a sustainable urban environment.

CONCLUSION AND RECOMMENDATIONS

The study has shown that urban heat island (UHI) effect exists in Ibeju-Lekki, while the Normalized Difference Vegetation Index (NDVI) and Land Surface temperature (LST) analyses show that areas with recent massive deforestation and rapid urbanization has higher land surface temperatures, thus experiencing more urban heat than the urban centers. Rapid physical development has played a dominant role on the thermal structure of the city causing the urban areas of Ibeju Lekki to be at all-time warmer than the surrounding rural areas, indicating the existence of urban heat island (UHI) in the study area. UHI intensity from this study shows an average of 4.7°C warmer than the rural areas in the last decade. The urban-rural temperature differences and their variation in seasons in the last thirty-six years (1984-2020) revealed that the maximum UHI intensity is dominant in Ibeju-Lekki with an average of 2.3°C. This study investigated the impact of land use and land cover changes on Ibeju-Lekki from 1984 to 2020 in Ibeju Lekki area, Lagos State. The land cover of Ibeju Lekki was substantially altered due to rapid urbanization and socio-economic development. Built-up areas increased to 20.9% from losing water bodies, forest/vegetation and bare surfaces during the study period. This has changed the surface radiative properties and consequently, affected the LST with an increasing trend thus creating a heat island effect in Ibeju Lekki.

Based on the findings from this study, there is need to incorporate GI through strategic and local plans into the future urban growth of Ibeju Lekki. This will ensure there is moderation in the conversion of vegetations and water bodies into physical and urban development in the study area. Policymakers and professionals in Ibeju Lekki area and in Lagos at large should be more concerned about future horizontal urban expansion and should consider vertical growth. The various stakeholders starting with the Local Government Area, Ministries, Departments and Agencies involved with city formation ecosystem and growth and should make a proper plan for green infrastructure such as environment-friendly construction, green building, and green or cool roof technology to reduce the urban microclimate warming effect, thus reduce the UHI effects. Growth management policies should be tailored toward vertical development. This will make room for the provision of open spaces and parks which are known to significantly moderate the effect of UHI in urban areas and consequently improve human wellbeing.

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DESIGNING FOR BIODIVERSITY - CONCEPTUALIZATION OF A SUSTAINABLE BUILDING ENVELOPE FOR A SINGLE-FAMILY HOUSE IN SWITZERLAND

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ABSTRACT

In urban areas, the promotion of biodiversity is gaining importance. On the one hand, biodiversity is dwindling due to intensive agriculture and the loss of habitats; on the other, cities offer a variety of suitable microclimatic conditions for plant communities and animals, which can be implemented through sustainable planning. This work aimed to develop a feasible concept for a building envelope to promote biodiversity, considering the surrounding habitats while addressing the specific needs of target animal species. This required a close cooperation between architects and environmental engineers. The study case selected was a family house in Gattikon (Zurich, Switzerland), belonging to the Swiss architectural office VBAU and subjected to renovation.

First, a site analysis was run to map local habitats, animal species occurrence and wildlife barriers, and simulate the time exposure to sunlight/shadows on the building envelope. Second, the criteria to rule out habitats and species was identified following an exclusion procedure. As a result, three habitats and six animal species were selected. Last, a concept for the design of the facade on the base of the ecological analysis results was developed. Bricks were used as suitable material to create a structured green facade that mimics the selected habitats while meeting the ecological requirements of the selected target plant and animal species.

In conclusion, considering both the habitats as a model and the life cycle of the target animal species enabled the selection of plant species to green the facades without missing the survival needs of animal species.

KEYWORDS

Animal-Aided Design, biodiversity, building envelope, bricks, ecological design, facade, green architecture, urban habitat

INTRODUCTION

The sixth mass extinction in world history is already underway [1]. In 2018, 35% of the animal and plant species recorded in Switzerland were considered endangered, missing or extinct [2]. For this reason, promoting and preserving biodiversity in construction and urban planning is becoming critical to fulfil nature conservation aims defined by the Aichi biodiversity targets [3]. Due to the increase of intensive agriculture and the sprawl of urban areas, built environments need to be considered when planning for the conservation of natural and semi-natural habitats. Therefore, planners can use near-natural landscaping, green roofs, and facade greening [4] not only to promote biodiversity, but also to provide benefits to people well-being, protect the buildings from weathering and UV radiation, as well as cooling the air, binding carbon dioxide and filtering pollutants and fine dust [5]. Nevertheless, to successfully incorporate biodiversity features into the building and to make it part of the whole design/ planning/ monitoring phases [6], the cooperation between construction planners and ecologists or environmental engineers through the whole project is crucial [7].

Species-based concept

A method used commonly to integrate biodiversity in designing practice is the *species-based* concept. In particular, considering that finances, time and, in some cases, knowledge are insufficient to develop measures for all threatened animal and plant species, it is common to privilege umbrella species, namely those whose protection would ensure that of many others [8]. For example, the protection of the capercaillie (*Tetrao urogallus*) has significantly increased the species diversity of endangered mountain birds with similar habitat requirements in the Swiss Pre-Alps [9]. In the urban context, the universities of Freisingen and Kassel in Germany have further developed the Animal-Aided Design (hereafter AAD) © method [10, 11]. In a nutshell, the AAD concept aims to integrate the requirements and characteristics of the target species into architectural and landscape design. To this end, AAD uses *species portraits* which contain the information necessary to the construction planner about the needs of the species across their life cycles [10, 11]. Nevertheless, it was shown that the use of this method might be not sufficient in terms of number of promoted species [12]. In fact, only few species genuinely benefit from it, and therefore the created habitat may not be as biodiverse as wished [8]. Instead, it might be more efficient to look at entire habitats [13].

Habitat-based concept

Another complementary approach was developed by Chartier Dalix Architects and applied in their project in Boulogne-Billancourt (Paris, France) in 2014. In this case, instead of explicitly integrating some animal's needs into their design, they designed a school building to imitate entire habitats: the facade was inspired by an old structurally rich stone wall with crevices and holes, providing space for vegetation, insects and small birds. On the green roof, plants were introduced so to resemble an oak-hornbeam forest typical to the French region of Ile-de-France near Paris, surrounded by a mesophilic herbaceous edge and a meadow [14]. The hope was, that the ecosystem would be able to develop independently. As a result, 70 new plants were recorded in 2016 in addition to those planted [15]. Even though this *habitat-based* concept encompasses several plant and animal species, a pure consideration of ecosystems might be too broad to protect certain target species [16].

Aim of the study

Combining the *species-* and *habitat-based* concepts, this study aims to overcome the identified gaps and explicitly embed biodiversity features on the building's envelope. Therefore, we intended to develop a method being 1) space- specific and able to select the habitats to replicate on the facade hosting target animal and plant species, 2) flexible enough to be implemented in other projects, fulfilling different requirements in other social and ecological contexts.

MATERIALS AND METHOD

The method itself is divided into three phases (Fig. 1): 1) the site analysis, 2) the selection of animal and plant species and 3) the design of a concept of the facade. The first two phases consisted of an analytical process based on collecting and interpreting the spatial data (species and habitat distribution). The third phase integrated the needs of the stakeholders (architectural firm involved) thanks to workshops and discussions facilitated by the selection of inspiring examples already planned or build.

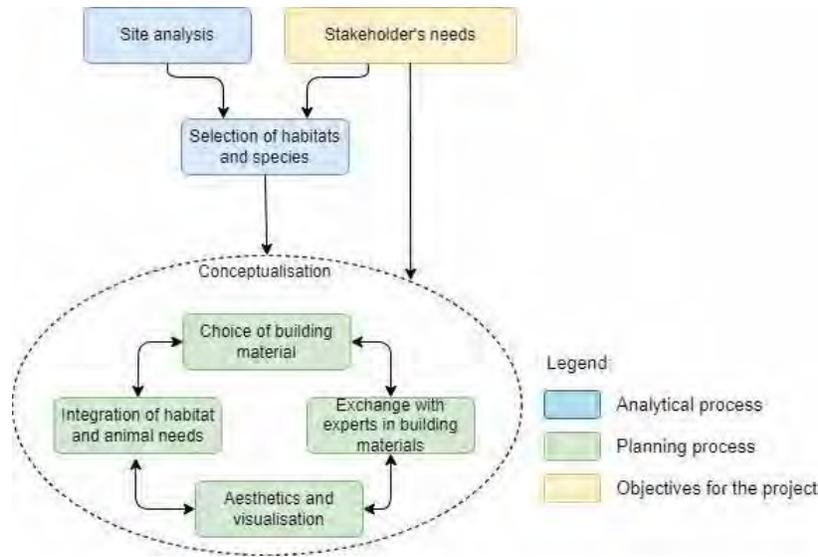


Figure 1: Overview of the work procedure

The study object was a single-family house (Fig. 3) owned by the architectural office VBAU Architektur AG, located in a small village of 2615 inhabitants within the municipality of Thalwil in Switzerland (Address: Waldstrasse 12, 8136 Gattikon ZH; Coordinates LV95 2693965.2E/ 1237350.04N) [17].



Figure 2: The study area (1.2 km²):
green = forest, blue = ponds,
red circle = house location (GIS Canton Zurich)



Figure 3: West side of the building
with access to the street
(photo: myHausverkauf)

Site Analysis

The first step was to analyse the surroundings of the house, namely the habitats and animals occurring in the nearby. For this, a study area of approximately 1.2 km² around the house was investigated (Fig. 2). Impenetrable barriers for terrestrial animals, like the highway, were selected as the borders [18].

To retrieve the animal species occurrence, the following open-source data repositories were screened: “<https://opendata.swiss/de>”, “<https://www.bafu.admin.ch/bafu/de/home.html>”, “<https://www.geolion.zh.ch>” and “<https://www.geocat.admin.ch>”. Moreover, the citizen science platform “<https://www.inaturalist.org>” and the Swiss Data centre Info Fauna (SZKF) – the data of the latter not shown in this paper - was used to retrieve animal and plant observations. All the data collected, including the surrounding habitats such as forests, ponds, settlements, barriers for animals (e.g., fences, walls, roads, and rivers) and access points to the building proximity were mapped and further analysed by means of the programme ArcGIS (ArcGIS pro advanced/2020/3.1). The satellite aerial view was retrieved from *swisstopo* “<https://www.swisstopo.admin.ch/de/home/meta/angebot/online-tools.html>”. Existing data from the local ecological network showing the barriers and the corridors for ground-based animals was added too [19].

Finally, the number of shading hours of the longest and shortest day of the year (December 22, 2020 and June 22, 2020) on each facade side of the building was simulated with the shadow analysis tool (Shadow analysis for Sketch Up/2020/2.1, Deltacode) on a 3D model of the building.

Habitat and target species selection

In the second step, the habitats to be replicated and the target animal species, to be promoted as part of this project, were selected. As for the target species, only those who were already observed in the area or whose occurrence was documented in other local initiatives were considered [18, 19]. The following criteria were used for a further selection of the target species:

- a. promotion requirements (at least one criteria must be fulfilled):
 - i. The species was one of national priority according to the Swiss red list [20, 21]
 - ii. The species was a relevant umbrella or flagship species.
 - iii. The species was already included in local biodiversity conservation measures, actions or plans from organisations or the municipality.
- b. compatibility between animals and humans (all criteria must be fulfilled):
 - i. Humans would not be drastically disturbed by the species (e.g., with noises or hazards or damaging the building with nesting).
 - ii. The species was observed living in the urban context.
- c. feasibility in the project (all criteria must be fulfilled):
 - i. The species was compatible with the other selected target species.
 - ii. The implementation of measures needed to support the species (e.g., food, breeding, shelter) was feasible and affordable.

A species profile for each target species was created following the AAD method and contained: 1) the description of the species most critical needs over the entire life cycle (e.g., pairing, raising cubs, adult phase and wintering), 2) species affiliation (e.g. related species), 3) the occurrence in Switzerland, 4) the preferred habitats and shelters, 5) social behaviour (e.g. live in colonies or as individuals), activity (i.e. nocturnal or diurnal), action radius or hunting ground, and 6) status (e.g. threatened). The information needed to build each species profile was based on scientific literature and on data published by recognised organisations such as the Swiss Society for the Protection of Animals (STS), the German Society for Nature Conservation (NABU) and local ornithological stations.

Habitats from the literature *Habitats of Switzerland* [22] and that are surrounding the study area or could be easily integrated on a facade (e.g., not habitats requiring a large amount of water) were considered for the project. Moreover, a benefits analysis was carried as a decision-making aid for complex problems. In the process, the potential solutions are broken down into different main- and subcategories, and their importance is assessed by using a semi-quantitative scale. Thus, aspects of different types (quantitative and qualitative) can be compared [23]. The habitats were assessed and evaluated in the following categories and subcategories in which habitat could score up to 100 points:

- The correspondence of the habitats with the temperature, soil acidity and nutrient content, precipitation and the shading of the site [24].
- The status (e.g., endangered, locally threatened) as well as the spatial distribution in Switzerland [22]. A higher score prioritised the habitats on the red list. In addition, the correspondence of the climatic zone of the habitat was also rated.
- The aesthetic potential value of the plant species. The habitats characterised by valuable plants for the residents got higher points.
- The feasibility of each habitat considering the initial and the maintenance costs.

The assessments were based on values taken from Landolt et al. [24] and Delarze et al. [22] as well as on the results of the shadow analysis. Due to the different shading, each side of the facade, the eaves and the ground was assessed individually. The habitats with the highest scores were selected and applied in the third and final exclusion procedure. Finally, the Landolt indicator values [24] of the plant species characterising each habitat [22] and the plants growing on sight were compared. The indicator values indicate various site conditions suitable for the plant growth on a scale of one to five and include parameters

such as: soil moisture (M), soil reaction (R), soil nutrient (N), light (L), temperature (T). This made it possible to exclude habitats whose indicator values hardly matched those of the existing plant species. The values of the temperature and light were particularly decisive for the exclusion procedure.

Design of a concept of the facade

To develop the concept of the new facade, a suitable building material was selected. The building material itself should consist of a natural raw material, be frost-proof and moisture-resistant, and minimise the impact on the environment. In addition, the material had to be adaptable to different design solutions. The whole process was carried out taking into account the advice of producers of different building materials and the VBAU architectural office.

Once the material was selected, similar projects like the structured facade of the Project in Boulogne-Billancourt from ChartierDalix served to inspire the design of the facade. The site analysis, the needs of the selected habitats and target species helped to determine the structure of the facades and the composition and thickness of the substrate. Finally, possible individual facade structures, the so-called *modules*, were created with the programme SketchUp (SketchUp/2020/2.1). Each element should provide either a shelter for the target species or allow the planting of the recommended plant species on the selected habitats. The next step was to determine which habitats and species were the most suitable for each side of the building and, thus, which *modules* should be used. The shadow analysis provided the basic clues to address this process. Plant species were divided into three categories based on their estimated growth: small (maximum height up to 50 cm), medium (maximum height between 50 and 100 cm) and large (maximum height more than 100 cm). Based on these size categories and the Landolt values for light (L), the habitat suitability for each vegetation type was estimated.

Finally, the elements were included in the 3D-model of the building and illustrations were created with Photoshop (Adobe Photoshop/2020/21.1.2).

RESULTS

Site analysis

The shadow analysis allowed to quantify to what extent the shading time on the north-facing facade (Fig. 4) is longer with respect to the south-facing facade (Fig. 5). As expected, the facades on the east and the west side are partly sunlit and shaded throughout the year.

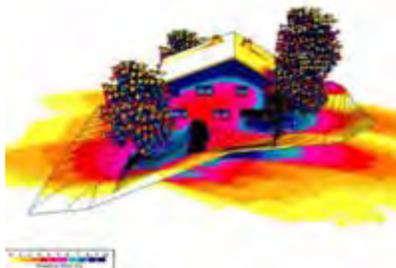


Figure 4: Shading duration on north-facing side (June 22 2020) is between 4 to 10 hours/day

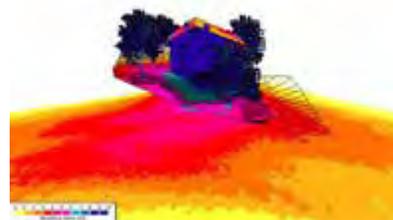


Figure 5: Shading duration on south-facing side (June 22 2020) is between 4 to 10 hours/day

Figure 6 shows the different habitat types and plant communities that have been surveyed for the site analysis. The forest covers 54% of the area on the map, whilst 4.2% of the considered surface is made of wetlands and 4.8% corresponds to agricultural zones. According to the site analysis, the following six habitats were relevant (habitat definition follows Mucina et al. 2016): Meadows on temporarily wet soils (*Molinion*), Reed swamp vegetation (*Phragmition*), Sedge-bed marsh vegetation (*Magnocaricion*), Basiphilous beech forest of temperate Europe (*Galio-Fagenion*), Acidophilous beech forest of Central Europe (*Luzulo-Fagenion*), Mesic mown meadow (*Arrhenatherion*). According to the Swiss Data centre Info Fauna (SZKF), more than 180 animal species were observed in the region within the last twenty years. The building is close to a conservation area with high biodiversity (in particular the pond named “Gattikerweiher”) where several corridors for terrestrial and flying animals are leading to the building (Fig. 7).

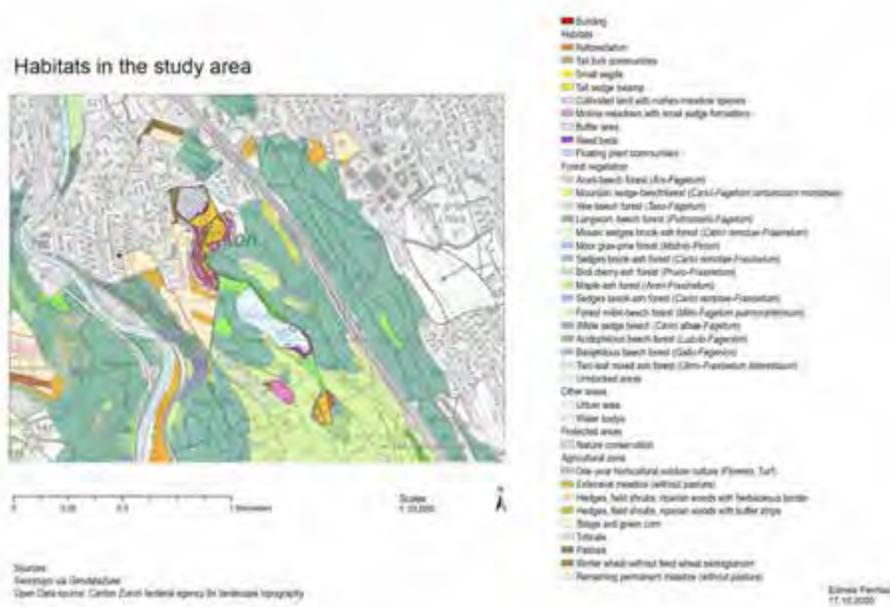


Figure 6: The habitat mapping of the study area in Gattikon shows more than 20 habitats and their plant communities (Data from Zurich federal agency for landscape topography, 2017)



Figure 7: Barrier map created via ArcGIS; green lines show the access to the building available for ground-based animals, the purple lines the access for flying animals (Data from Zurich federal agency for landscape topography, 2017; municipality Thalwil, 2017)

Selection of the target species and habitats

Of the observed animal species in the study area, the following six target animal species were selected based on the declared criteria (promotion requirements, compatibility between animals and humans and feasibility in the project): greater mouse-eared bat (*Myotis myotis*), common redstart (*Phoenicurus phoenicurus*), common hedgehog (*Erinaceus europaeus*), common house Martin (*Delichon urbicum*), masked bee (*Hylaeus* sp.), and sand lizard (*Lacerta agilis*).

The sand lizard, for example, was selected because it was observed several times in the study area, it is considered vulnerable [20], and it is also an umbrella species [25]. Other animal species, such as the sand bees (*Andrena* sp.) and natterjack toads (*Epidalea calamita*) benefit from implementing the needs of the sand lizard, as they live in similar site conditions. In addition, the sand lizard does not cause any damage to the building, it adapts to settle in urban areas, and it needs specific site conditions that are feasible to apply in the project.

For each selected animal, a species profile was created. The crucial information – namely the critical location factors by life stage – from the sand lizard's profile is shown below as an example:

- **Egg-laying and hatching:** A suitable site for oviposition is characterized by low vegetation and requires a substrate that is loose and aerated such as sand, gravel, or lava rock. This area should be around 1-2 m² large, 0.3 m deep, and be in a south-westerly exposition [10, 26].
- **Adult:** The sand lizard depends on wide temperature ranges in their environment. Therefore, habitats hosting patchy vegetation including shady and sunny areas are suitable. On the one hand, the sand lizard needs vegetation-dense structures to hide from predators such as bushes or tall grasses; on the other hand, they prefer low vegetation ground for hunting and foraging. Materials that heat up quickly are needed in the habitat, such as dead wood, stones, or dry vegetation. At night, sand lizards retreat into crevices or underground tunnels. The predators of adult sand lizards are the smooth snake, various mammals such as cats or martens, magpies, birds of prey, or crows [10, 26, 27].
- **Winter quarters:** From the end of September to April, sand lizards go into hibernation. For this purpose, cavities and tunnels are dug, or crevices are used. The hibernation site must be sufficiently insulated and frost-free. A south-facing slope is usually suitable [10, 26].
- **Territories and pairing:** Young lizards need to find their territory to stay for their whole lives. The males defend their territory against other sand lizards, whereas the females sometimes share their location. The sand lizards mate from mid-April to mid-May [10, 26].

Of the assessed habitats, the three following habitats were selected based on the declared criteria (the correspondence of the habitats with the on-site factors, the status of the habitat, the aesthetic potential values, the feasibility): *Centrantho-Parietarium* for the south-facing side, *Trifolium medii* for the west/east-facing side and the herbaceous layer of *Galio-Fagenion* for the north-facing side. The process to get this result is explained in the following paragraph: First, two out of the six habitats in the study area (*Phragmition* and *Magnocaricion*) were excluded because of the high amount of water required. The remaining four habitats were: *Molinion*, *Galio-Fagenion*, *Luzulo-Fagenion* and *Arrhenaterion*. Second, the following habitats were also considered, because they were judged to be compatible with the climatic conditions of the building envelope or because they already occur in urban areas: *Geranion sanguinei*, *Berberidion*, *Galeopsion segetum* and *Centrantho-Parietarium* for the south-facing side; *Trifolium medii* for east/west-facing side, *Cystopteridion* for the north-facing side. Third, the habitats were scored for each side of the building in each category as listed in the method. For the selection process of the habitat, the results concerning the south-facing side are shown as an example in Table 1.

The scale went from 1 to 100, whereas the highest scores point out that the habitats were more suitable for the facades. Last, the Landolt values of the plants on site were compared with the ones occurring in the most suitable habitats (Table 2). The habitats with the most overriding numbers were finally selected.

Table 1: Final results of the benefit analysis of each selected habitat for the south-facing side of the facade.

| Name | Eaves | Facade | Ground |
|------------------------|---------------------------|-------------------------------|-------------------------------|
| Geranium sanguinei | 53.1 | 56.3 | 45.1 |
| Berberidion | 48.2 | 63.8 | 63.2 |
| Galeopsis segetum | 46.9 | 61.1 | 55.3 |
| Centrantho-Parietarium | 51 | 82.2 | 72.2 |
| Selected | Geranium sanguinei | Centrantho-Parietarium | Centrantho-Parietarium |

Table 2: The Landolt values of the plant species compared with the reference plants on the south-facade [22].

| Name/ Index | Moisture | Reaction | Nutrient | Light | Temperature |
|------------------------|----------|----------|----------|--------|-------------|
| Centrantho-Parietarium | 1 to 3 + | 4 to 5 | 2 to 3 | 3 to 4 | 4+ to 5 |
| Geranium sanguinei | 1 to s 3 | 3 to 5 | 2 to 4 | 3 to 4 | 3 to 5 |
| Reference Value | 2+ to 3 | 3 | 3 to 4 | 2 to 4 | 3 to 4+ |

The compatibility between habitats and animal species was verified throughout the whole process. In Table 3, the target animal species are listed in their suitable habitats.

Table 3: Compatibility between selected habitats and target animal species [21, 20].

| Habitat Type | Animal species |
|-------------------------------|---|
| <i>Galio-Fagenion</i> | <i>Myotis myotis</i> , <i>Lacerta agilis</i> (only in forest edges), <i>Erinaceus europaeus</i> |
| <i>Trifolium medii</i> | <i>Phoenicurus phoenicurus</i> , <i>Lacerta agilis</i> , <i>Hylaues sp.</i> |
| <i>Centrantho-Parietarium</i> | <i>Lacerta agilis</i> , <i>Hylaues sp.</i> |

Designing and conceptualization

While selecting the materials to be used in the design of the facade, only those with a low environmental impact were considered. In a study by KBOB, rammed earth, wood, sand-lime and bricks were found to have a lower impact on the environment [28]. Bricks were finally chosen as the most suitable material because they are widely used in architecture and they are available in several shapes and sizes. The 'structural liberty' offers a wide range of possibilities to realize facade greening and nesting sites as part of the architecture. The chosen brick type was frost-resistant and contained some holes able to host some substrate to favour plant establishment and growth [29]. To seal the exposed bricks, a plate or mortar would prevent the substrate from falling out. The bigger grip hole of the bricks (88×33×135 mm) gives enough space for plants to grow on lightweight substrate mixtures. The smaller holes provide space for smaller organisms like mosses. Near-natural soil conditions are mimicked by creating a complex combination of depths and layers of the substrate as it is commonly done for green roofs [30]. Every facade side (Fig. 14, Fig. 15) was designed according to the selected habitat and needs of the target animal species. Therefore, each side had different *modules* (some examples Figure 8 -13).

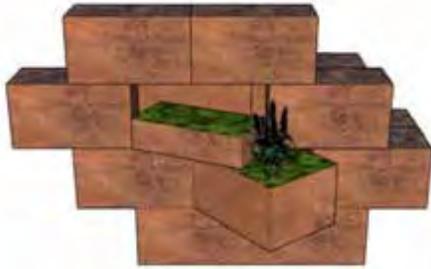


Figure 8: The oversized grip hole in the center provides space for medium-sized plants. This design leans to more structure in the facade with small crevices.
Possible animals present: insects
Substrate depth: 14-20 cm



Figure 9: The exposed bricks are placed on top of each other, therefore doubling the substrate thickness. This element is particularly suitable for larger plants or plants that prefer wetter soils.
Possible animals present: insects, spiders, snails, butterflies, small birds, sand lizards.
Substrate depth: 27 cm.

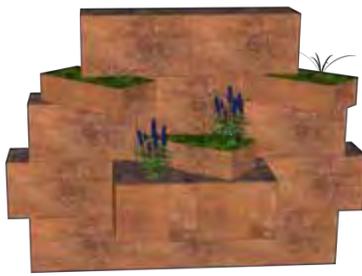


Figure 10: Some bricks lie diagonally above the bigger bricks. This creates an even more complex structure with varying substrate depths.
Possible Animals: insects
Substrate depth: 14-20 cm



Figure 11: Two thin exposed bricks are clamped between two rows of bricks. In this case, these are custom-made (300×120×50 mm). Alternatively, a wooden board can be used. House martins use this board for their nests.
Possible animals: House martins



Figure 12: The element contains a nesting box (180×240×200 mm) for the redstart. The nest is protected by a cut wooden board and offers access by means of an oval entrance hole (200×32 mm).
Possible animals: Redstart, other birds

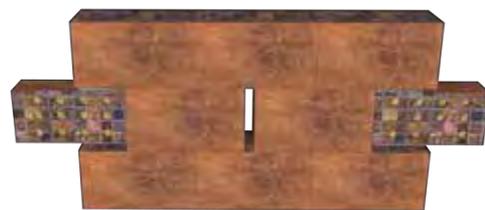


Figure 13: The module provides a gap that can be used by bats. In addition, two exposed stones are turned upside down and serve as an insect hotel. For this purpose, small plant stems are placed in the holes of the exposed stone.
Possible animals present: insects, spiders, wild bees, bats



Figure 14: On the west-facing side, several brick beds are attached to columns so that larger plant species characteristic of the habitats *Trifolion medii* and *Galio-Fagenion*. are integrated into the building envelope. Among others: the blackberry (*Rubus fruticosus*), the hairy sedge (*Carex hirta*) and the spiky rapunzel (*Phyteuma spicatum*). The containers shade the facade behind them, which provides a semi-shaded and sheltered niche for the redstart. Plants of the *Trifolion medii* occur also in the modules near the balcony. On the upper edge of the facade, there are built-in structures on which house martins build their nests.



Figure 15: On the south-facing side of the facade, the habitat *Centrantho-Parietarion* is imitated. Apiaceae, such as the wild carrot (e.g. *Daucus carota*), are planted to provide food for the masked bees. The spars in the modules can be used as summer roosts by smaller bat species such as the common pipistrelle. On the top floor, an entrance is built into the attic for the greater mouse-eared bat, separated from the space occupied by humans.

DISCUSSION

The aim of this study was to develop a method for incorporating biodiversity into the design of a building from the outset, using a real study case. The method was inspired by the basic idea of not only *design with nature*, as the Scottish landscape architect McHarg [31] described in his ecological planning methods, but to go further and *design for nature* [32]. The base of *design with nature* is that the designer needs to understand the area through analysis of environmental factors such as soil, climate, hydrology, etc., then decide where and how the urbanization should be implemented to reduce the influence on the most vulnerable ecosystems [31]. *Design for nature* builds on and expands this concept by using ecological digital models and combining them with *sustainability criteria*, *socioeconomic development goals* and *conservation targets* [32]. In this framework, technologies such as GeoBIM (in which BIM is integrated with GIS) have become a tool that can perform accurate urban analysis and lead to sustainable development [32]. Tackling sustainability, urban development can aim to meet both the SDGs and the Aichi Targets.

The interdisciplinary knowledge required to implement the goals of *design for nature* and the complexity of biodiversity makes practical implementation difficult for planners, architects and biologists. Therefore, trying to combine the *species-based* concept and the *habitat-based* concept represents a promising way of implementing part of the *design for nature* idea into practice without GeoBIM computer models, because they balance their weaknesses out and fill knowledge gaps.

Data collection and site analysis

The building of our case study is located near a nature reserve of national biological importance. In addition, the different shading conditions allow for a variety of dry and wet microclimates on the building. Despite the favourable conditions, the risk of misinterpret data or neglect factors remains real. For example, certain species may not settle in one area because of underestimated disturbance factors such as loud noises or pets. Also, only the shadow analysis and the indicator values analysis of the existing plant species served as information on the location. Furthermore, the data of the animal observations are taken in a range of 20 years. Therefore, it can be assumed that the species which were observed several times in the last 20 years, such as the sand lizard (*Lacerta agilis*), have a stable population. However, it is unclear if birds observed only once, such as that of the grey woodpecker (*Picus canus*, observed in 2008) or the cirl bunting (*Emberiza circlus*, observed in 2013), will occur again in the future.

Selection of animal species and habitats

The site analysis revealed a large range of animal and plant species that could have been eligible in this project. The difficulty, therefore, laid in defining the most effective and objective selection criteria possible for promoting biodiversity on the facade. Other projects/concepts, such as AAD and Projects from Chartier Dalix, helped to form these criteria as they already had monitoring data that allow to demonstrate their success. A main difference from these was that the selection process for the target animal species and the habitats ran parallel, therefore the two methods were mutually dependent and supportive. The fact that target animal species were supposed to occur in the selected habitats simplified and accelerated the exclusion process.

Designing and conceptualization

The design concept has proven to be flexible and rich in structure. The assessment of whether the building material was suitable for a structurally rich, densely greened facade was mostly based on the advice of experts for the respective building material. The design concept can also be applied to other projects and extended with additional *modules*. In addition to flexibility, the environmental compatibility of the material was crucial. Therefore, the UBP value was used as an approximate guideline to compare ecological building materials, even if it is not an exact value[33].

To minimize uncertainty regarding waterlogging and frost damage, water absorption capacity and frost resistance were considered in the selection of bricks. When creating the modules for the facade, care was taken to ensure that the requirements of the species issuing from the species profiles were met on the facade and in the garden (e.g., entrance holes in the nesting box), but it cannot be guaranteed that the desired target species will settle there. In further studies, the focus could be on the optimal size of the holes containing the appropriate substrate thickness to host the target plant species. In this work we assumed that a plant up to 50 cm height could be planted in the brick hole area of 88×33mm. An irrigation system and the maintenance of the facade has to be tested in further studies.

CONCLUSIONS

This study aimed to successfully design a biodiversity-friendly facade using a combination of the *species-based concept* and the *habitat-based concept*. In the considered project in Gattikon (ZH, Switzerland), it has proven advantageous that a broad spectrum of animal and plant species was covered in the planning by imitating the habitats and important promotion measures for the target animal species were planned at the same time. The advantage of combining these methods became clear when promoting target species for which there was less knowledge about their life cycle needs. In this case, promotion using only the *species-based concept* is more demanding when the information on certain target species was difficult to find. By mimicking the three habitats of *Trifolion medii*, *Galio-Fagenion* and *Centrantho-Parietation*, which have a variety of suitable flowers for wild bees, the facade became more attractive for wild bees and therefore increasing the chance that the bump-masked bee would also settle there. The *habitat-based concept* in turn benefited from the *species-based concept* in that more details could be planned.

In the next step, to scientifically consolidate the findings of this work, the facade concept needs to be tested and monitored experimentally, as well as plant species growth and dynamics, and material behaviour.

AUTHORS' CONTRIBUTION

CC and Pascal Geiger (PG) arranged the thesis initial framework (topic, generic aims and identification of the study case). BD and EP run the literature review, developed the method, run the analysis, and ideated the design solutions under the supervision of CC and PG. EP and BD wrote the first draft of the manuscript. BD, EP and CC carried out the final revision. All the authors shared the final version of the manuscript.

ACKNOWLEDGEMENTS

This paper is based on the bachelor theses of BD and EP', submitted in partial fulfilment of the requirements for the degree in Natural Resource Sciences at the Zurich University of Applied Science (ZHAW), under the supervision of Dr. Chiara Catalano (ZHAW) and Pascal Geiger (VBAU). The authors would like to acknowledge the VBAU Architecture Office, in particular Pascal Geiger, Etienne Vetterli, and Moreno Santoleri for their support and cooperation. For the provision of data and advice the authors thank Jannick Arment (UNIKA), Oliver Bachmann (Planikum GmbH), Elias Bader (Verein für Fledermausschutz), Krystian Gryzbek (Küng Holz AG), Sarah Hummel (SZKF), Esther Keusch (municipality of Thalwil), and Hans Schmid (Sempach ornithological station). Special thanks go to Pascal Ochsner (ZHAW) for his help in editing the GIS maps, as well as to Seline Durrer and Laslo Vetter for tips on the use of Adobe Photoshop. In addition, we thank Roberto Cazzato (Keller-Unternehmung AG) for sending us some bricks and advice. Finally, Dr. Salvatore Pasta (CNR-IBBR, Palermo, Italy) is kindly acknowledged for his suggestions and remarks which improved the final version of the manuscript.

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BEIRA CITY IN MOZAMBIQUE AND CLIMATE CHANGE

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ABSTRACT

Given the objectives of the United Nations Development Agenda for 2030, which refers to the sustainable principles of a circular economy, there is an urgent need to improve the performance of the built environment. Existing buildings and urban infrastructure must be preserved and improved to reduce their environmental impact in line with the need to reverse climate change and reduce the occurrence of natural disasters. Architecture is often discussed in terms of what the buildings look like from the outside. However, how buildings and cities work has much more to do with how they shape and limit urban spaces. It is essential to identify what is wrong with the current built environment. This article aims to study and define strategies that promote urban rehabilitation in Beira, Mozambique, considering local climatic, architectural, and social issues and contextualize its importance with global climate change, emphasizing energy efficiency, water efficiency, and waste management. Currently, Beira is one of the African cities most vulnerable to climate change, the most recent of which was cyclone IDAI in 2019, one of the most devastating because there are records in the southern hemisphere with winds that reached 200 km/h, as well as tropical storm CHALANE, and cyclone ELOISE in 2021. Beira's importance in the Mozambique commercial context, and even in Africa, is recognized for its strategic location and existing connections, where the port is essential in developing the urban structure. Therefore, it is necessary to incorporate the current strategies to achieve sustainable growth. The city must be reorganized, restored, and set in a structured and resilient manner, considering new urban trends based on climate change. It is intended to develop rehabilitation strategies in the areas of requalification of resilient urban spaces, thermal comfort of buildings, energy, water supply, and sewage, which made it possible to establish the expected improvements resulting from the action to be taken and to explore community and individual strategies.

KEYWORDS

Climate change; Climate adaptation; Urban rehabilitation; Resilience, Mozambique.

INTRODUCTION

Climate change is responsible for several events including extreme temperatures. In recent years, Africa has experienced extreme temperatures above the pre-industrial levels. Despite its low contribution to greenhouse gas emissions and global warming, Africa is among the world's regions that suffer the most from climate change [1,2].

Over the past 40 years, the world has experienced an increase in the temperature. The past six years have been the warmest. 2016 and 2020 are the hottest, recording 1.29 °C and 1.27 °C higher than the pre-industrial period (1850-1900), respectively [1,3].

Approximately 90% of anthropogenic heat is absorbed by the oceans [4,5], and the western part of the Indian Ocean has the fastest warming, with an average summer rise of 1.2 °C [6]. This warming is visible in the increased frequency and intensity of extreme weather events in the nearby regions [7].

In 2019, a record of eight tropical cyclones developed over the Indian Ocean affected various locations in Asia and East Africa. From March to April 2019, Mozambique was hit by cyclones Kenneth and Idai [8], the strongest tropical cyclones on record, overcoming the severity of the February-March 2000 season, during which the country was devastated by two cyclones, ELINE and HUDAH [9]. The number of such events is likely to increase in the future [5]. In 2021, The tropical storm CHALANE and cyclone ELOISE in 2021 [10]. Figure 1 illustrates the evolution of natural disasters in Mozambique between 2000 and 2021.

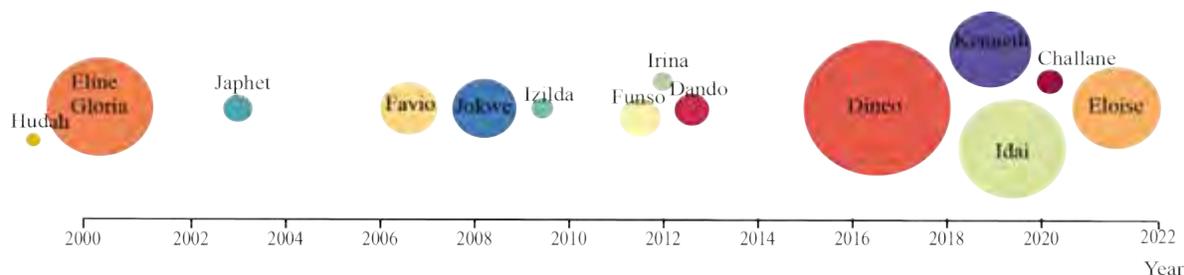


Figure 1. Evolution of natural disasters in Mozambique: 2000-2021 [8–18]

In this context, climate change is a consequence of changes in average temperature, an increase in extreme events, increased climate variability, and vulnerability to socioeconomic activities. Thus, as part of climate justice, developed countries have a moral obligation to support countries that do not have the resources to adapt to climate change and are most affected by it [5].

The recent Glasgow Climate Pact (COP26) is a breakthrough, but decarbonizing efforts are insufficient to limit the global temperature increase to 2 °C [19]. However, there is no explicit support for the vulnerability of a country to climate change.

In cities worldwide, particularly on the African continent, there is an increasing concern about developing strategies to adapt to climate change, focusing on avoiding or limiting the impacts of cyclones, tropical storms, heavy rains, rising sea levels, heat waves, and water supply restrictions [20]. Climate change brings new challenges to the existing ones in Africa, where adaptation is at the top of the development plan. Adaptation is needed to build cities' resilience to climate change, which is characterized by many informal settlements [21].

Despite frustrations with the slow pace of global action on climate change and sustainable development, as awareness increases about the urgency of responding to climate change and promoting sustainable development, few robust initiatives decisively shift urban development towards a sustainable, resilient, and low-carbon direction. In general, cities worldwide have different starting points and conditions. Urban areas must be attractive, inclusive, sustainable, resilient, thriving, innovative, local, national, and international. However, while many sustainable urban transformation initiatives exist, there are only examples in which transformative change has been appropriately connected to sustainability goals to realize strategic potential [22].

Sound resource management and design of urban structures to mitigate and adapt to climate change are critical urban challenges. Urban systems must be multifunctional and integrate ecological, economic, recreational, and aesthetic value. Key areas include shifting urban energy systems towards renewable sources, increasing energy and material efficiency, ensuring sustainable management of the quality and sufficiency of water supply, and transforming waste management into sustainable material and energy usage [23].

Buildings are an integral part of the urban space. The main challenges are creating accessible, attractive, efficient, comfortable, and sustainable buildings that help their occupants mitigate contributions to climate change, use renewable energy, reduce the excessive consumption of materials, and incorporate reuse principles. The effectiveness of the proposed strategies also requires an understanding of human behavior and consumption in the context of the built environment [24].

It is also essential to have agricultural adaptation to climate change in different continents. Studies indicate that South Asia and South Africa are two regions that, without sufficient adaptation measures, are likely to negatively affect several crops that are important to the large human population facing food insecurity [25]. In addition to nutritional problems caused by food shortages, diseases such as cholera, diarrhea, and malaria can increase owing to more frequent and severe floods and droughts, thus affecting urban populations in high-risk areas [26].

An estimated 54 million Africans live in vulnerable coastal areas [26], and the principal risks of climate change are water stress, sea-level rise, floods, drought, heat waves, and dust-sand storms.

Nevertheless, building resilience to climate change in cities is intricately linked to how the global world can resolve the challenges of rapid urbanization and accelerated global temperature changes [27,28].

In this context, Beira is a colonial city established as a seaport that exports raw materials in Mozambique and is one of the most vulnerable cities in the world to climate change [16]. Mozambique is a country on the east coast of southern Africa bordered by Tanzania, Malawi, Zambia, Zimbabwe, South Africa, Eswatini, and the Indian Ocean section known as the Mozambique Channel to the east [29].

The city of Beira, a coastal city in central Mozambique according to the 2017 census, has 533,825 inhabitants, is the capital of the province of Sofala, and is characterized by a tropical savanna climate the designation “Aw” according to the classification Köppen-Geiger [30].

METHODS

However, the precise magnitude of the future climate change remains unclear. No scientist has devised a page of equations to explain the global atmosphere. The climate system is extraordinarily complex for the human brain to gain simple insight [17,31].

This study conducted a literature review, analysis of morphological variations using geographic management systems, topographical surveys of specific areas, and interviews with residents and public managers.

The research was conducted qualitatively, and the material was generated from Scopus and the Web of Science using a keyword search strategy. The keywords used were climate change, resilience, cities, and Africa, and 20 of 242 articles were considered. Studies published in languages other than English have not been considered.

Residents were contacted through anonymous and randomly unstructured interviews using news from local newspapers to address climate change in Beira. This type of interview allowed greater spontaneity. It does not have a pre-established script, making its model open to questions, such as a conversation, offering freedom, and allowing the modification of questions according to the course of the conversation.

Collecting data through geographic information systems over the last 20 years has been a comparative analysis of variations in coastlines and mangroves and reports from local and international institutions.

RESULTS AND DISCUSSION

Mozambique ranks among the top three African countries most exposed to multiple climate hazards [29], where poverty and war have caused people to migrate to cities. No previous effort has been made to expand cities to accommodate people on this scale. The rapid growth of these urban areas has been exacerbated by problems associated with urban waste, sanitation, and drinking water, resulting in significant environmental changes. Consequently, health problems in vulnerable environments are increasing. In addition, these are densely populated urban centers situated near the coast, making them vulnerable to projected global warming and the consequent rise in the sea level.

Thus, Beira faces the severe challenge of rapid urban growth associated with its high exposure to climate change. We are creating a fluid scenario for decision makers, fundamentally in the issues of resilience in the face of intensifying climate stress and the management of resources and infrastructure. The dilapidation of the city's buildings, disorganized suburban housing, and poor sanitary and environmental conditions have caused growing concern and the reason for this study.

Beira is the fourth largest city in Mozambique, where the Port of Beira is the second largest, and it has a strategic location for movement to and from nearby landlocked countries. It is in the country's central region, the capital of Sofala Province, where the Pungwe River meets the Indian Ocean, and is 319 km from the Zimbabwean border. The groundwater levels at the surface were the same [32]. Suburban and rural areas consist of adobe houses, mostly without electricity or sanitary infrastructure, in which vegetable gardens play a significant role.

In figure 2, we have a general map of Beira, where a clear urban structure is evident, highlighting the Ponte Gea neighborhood in the right image. This map shows the contrast between orderly areas and areas of disorderly expansion (informal areas), which present deficiencies in the basic infrastructure.



Figure 2. General map of Beira (left) and the Ponte Gea neighborhood (right).

The period of African modernism is one of the essential characteristics of the city of Beira and is characterized by a rich architectural heritage. We can highlight some emblematic buildings in figure 3 of the city, such as the railway station and the Alto da Manga Church.



Figure 3. Railway station (left) and Alto da Manga church (right).

Since 1960, average temperatures across the country have increased by an average of 0.9 °C (0.15-0.16 °C per decade), especially during the rainy season. Over the last 40 years, the number of hot days increased by 25. Although average rainfall decreased by 3.1% per decade, the proportion of days with heavy rainfall increased by 2.6% [33]. The climatic data for 1991–2020 included the minimum, maximum, and average temperatures per month and annual average, monthly precipitation, and annual average, as well as the average seawater temperatures [34], where the minimum temperature was 17 °C between June and July, and the maximum temperature was 31 °C between November and March. The average annual temperature is approximately 25 °C. Rainfall is almost 1,600 mm/year, and the average annual seawater temperature is approximately 26 °C, with the coldest months from July to September at 24 °C.

The global mean sea level has risen between 21 and 24 cm since 1880, where the global mean water level in the ocean was observed to rise by 3.6 millimeters per year from 2006-2015 to, which was 2.5 times the average rate of 1.4 millimeters per year for most of the 20th century. It is estimated that the global average will increase by approximately 30 cm above 2000 levels by the end of the century, even if greenhouse gas emissions follow a low path in the coming decades [35].

The shoreline variations between 2004 and 2021 are shown in figure 4. The most notable and alarming variations are marked in red in the initial shoreline position in 2004, and in blue in the current position in 2021, with variations of up to 150 m over 17 years. Apart from the further variation caused by coastal erosion and median sea-level rise, other phenomena were also considered, such as a decrease in the pre-existing mangal area in this zone and an increase in natural disasters that destroy some of the protective structures.



Figure 4. Coastal erosion near the Chaimite and Ponte Gea neighborhoods (Beira City).
The red line represented the initial profile in 2004.

Figure 4 shows a significant reduction in the mangrove area between 2004 and 2021 (green). Mangrove forests are among the most productive and biologically essential ecosystems globally, [36] because they provide essential ecosystem goods and services for human society and coastal and marine systems.

In terms of relief, Beira City has a minimum altitude of 0m (figure 5). The increase in sea level thus increases the vulnerability of the city's coastline to erosion and flooding and, at the same time, promotes saline intrusion. Thus, a part of the city is below sea level, so it is exposed to frequent floods that can be disastrous when a cyclonic situation is combined with high tide.



Figure 5. Topographic map City of Beira, altitude, relief (adapted) [37].

In Mozambique, there are eight predominant mangrove species (*Avicennia marina*, *Rhizophora mucronata*, *Ceriops tagal*, *Bruguiera gymnorrhiza*, *Sonneratia alba*, *Lumnizera racemosa*, and *Xilocarpus granatum*) [38,39]. Their complex rooting can break and slow abrupt tidal movements, thereby forming a natural barrier that protects coastal communities.

Mangroves also protect coastal areas against natural disasters, such as tsunamis, cyclones, and erosion resulting from sea-level rise. The expected increase in extreme events owing to climate change is significant for disaster risk management [40].

Mangroves also help protect coral reefs, seagrass mats, and shipping lanes by trapping sediments transported by upland erosion. This is critical for preventing and reducing coastal erosion, and provides nearby communities with protection from the effects of wind, waves, and water currents. They support the conservation of biological diversity by providing habitats, spawning areas, nurseries, nutrients for several marine and aquatic species, and food, medicine, fuel, and building materials for the local communities.

Beira is constantly subject to flooding because it is below mean sea level, which makes it challenging to drain rainwater during storms. Inward flow of seawater during storms. Mangroves play an essential role because they dissipate wave energy, cushioning the impact of rising sea levels and the wave action associated with climate change [41].

As indicated above, the city of Beira is in a zone where there is a tremendous impact of climate change, acceleration of natural disasters caused by climate change, and a lack of adaptation of urban structures and infrastructure. Consequently, they inevitably experience natural disasters. This implies some changes in urban infrastructure and buildings. Undoubtedly, these changes imply risks to economic activity and opportunities.

To preserve Beira's built heritage from the tropical modernist movement, and at the same time ensure safe conditions for its users, more adequate facilities for water availability and treatment are needed, such as adapting buildings to new climatic conditions (roofs, frames, portable protection devices, insulation, etc.), flood prevention (coastal defenses, network of retention basins, and other infrastructures), sustainable urbanism, consistency with the reduction of water availability, and the inclusion of bioclimatic design.



Figure 6. Example of damaged roof (left) and damaged infrastructure (right) in Beira.

Figure 6 shows some of the most recurrent examples of destruction resulting from Cyclone Idai's 2019 passage. As far as buildings are concerned, the most vulnerable elements in buildings are window frames and roofs, given that the types of roofs and structure are not adapted to current requirements. Most roofs are made of fiber cement or metal sheets on wooden structures that are not prepared for hurricane winds or precipitation. Signs of infrastructure destruction are evident, particularly in the coastal areas.

These points were reflected in the interviews. And alert to a need for appropriate measures where the public sector must provide adequate knowledge of impacts and the best adaptive strategies and create an adequate regulatory framework and incentives to encourage long-term consideration of current decision-making.

Bearing in mind the above, it is possible to propose some strategies, which could be developed, for the city's adaptation to climate change: mangrove reforestation and dune recovery, as a way to protect erosion and sea overtopping, especially in cyclonic events or heavy rainfall coincident with high seas; implementation of urban green infrastructure to improve soil permeability and reduce urban heat islands, protecting non-urban areas with a high level of evaporator surfaces and ensuring hydrological regimes; promote a compact, mixed-use urban form design that uses land efficiently, thereby promoting an increase in the mix of land uses (in terms of number and diversity of land use types), with particular attention to zones of disordered growth; assigning a fundamental and prominent role to green spaces as nodes of green infrastructure and elements of climate change adaptation policies; creation of specific regulations that promote the resilience of buildings to be rehabilitated and for new construction, vulnerable to the increase of cyclonic events, such as the roofs of buildings and window frames; promote electricity supply infrastructure, resilient telecommunications reducing overhead distribution.

CONCLUSION

Adapting to climate change is an essential aspect of a city's development program. In the case of Beira, the impacts of climate change cannot be underestimated, particularly when a considerable part of the population lives under conditions of vulnerability to the impacts of climate change. Although good practices are in place, city-wide adaptation is essential.

Given the goals of the United Nations Development Agenda for 2030, which refer to the sustainable principles of a circular economy, there is an urgent need to improve, renew, and protect the built environment.

Thus, the adaptation of the city of Beira to climate change must consider the protection and reforestation of mangroves in the coastal zone, the adaptation of urban infrastructure, development of rehabilitation strategies to rebuild resilient urban spaces and buildings, thermal comfort of buildings, energy, water supply, and sewerage; exploring community and individual strategies; community adaptation with good practices; and institutional adaptation to policy and regulatory responses are essential for increasing adaptation to climate change.

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BIKING AND WALKING WITH COVID-19: THE COMPARISON OF ACTIVE OUTDOOR ACTIVITIES BEFORE AND DURING THE PANDEMIC IN YOGYAKARTA

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ABSTRACT

During the COVID-19 Pandemic, people are forced to stay at home by the government. This restricts them to go outside which seems to make them bored. In Yogyakarta, Indonesia, there was a moment when more people than before doing biking and walking in a certain area of the city during the pandemic. This is an odd moment because active outdoor activities were not so popular for Yogyakarta citizens. This phenomenon is unique because before the pandemic when people are free to do outdoor activities, only a few of them did biking and walking. On the contrary, during the pandemic when they are restricted to do outdoor activities and forced to stay at home, most of them do the opposite. Hence, this study aims to analyse the pattern of people doing biking and walking before and during the COVID-19 in the Yogyakarta area. It focuses on the comparison of the rate of the activities and the preferred routes in doing the activities. This study gathers biking and walking activity data from Strava, mobile app-based software that records its user's biking and walking activity, from January 2019 to December 2020. It is then analysed using the spatial analysis method. It results in the influence of the stay-at-home policy and COVID-19 pandemic to the increasing rate of biking and walking activities and the user's preference in choosing the route. It shows that more people do biking and walking during the pandemic in which they prefer to do the activities in either the peri-urban, sub-urban, and recreational area of Sleman Regency, Yogyakarta.

KEYWORDS

COVID-19 Pandemic, Strava, Heatmap, Spatial Distribution, Urban area, Sub-Urban area

INTRODUCTION

Indonesia, same as most countries in the world, is facing the Novel Coronavirus Disease 2019 (COVID-19) which was firstly reported by the Ministry of Health Republic of Indonesia on March 2nd, 2020, revealing the first case of COVID-19 in Depok City. Since then, the confirmed case was rising until, as of the end of 2020, more than 600,000 cases were confirmed and almost 20,000 deaths confirmed [1]. On March 31th, 2020, the President of the Republic of Indonesia issued a government decree number 21/2020 on the implementation of “Large Scale Social Restrictions” (LSSR) to handle the COVID-19 pandemic. It becomes the guideline for government officials across Indonesia to reduce the virus spreading domestically by limiting mobility and activities of the citizens within and inter the city. This includes school and work from home, restriction on religious activities, and restriction on activities in public places. Therefore, people are forced to stay at their homes and limit their activities outside. This study refers to such policies as the “stay-at-home” policy.

However, an odd phenomenon emerged during the restrictions period. From around June 2020, more people were doing outdoor physical activities, such as biking, walking, and running in Indonesian urban and sub-urban areas (this phenomenon was captured from both direct observation and several local news (i.e. [2], [3], [4]). It contradicts the usual number of outdoor physical activities done by Indonesian. A survey shows that more than 50% of Indonesian only done exercise/sport activities for either less than an hour or one to two hours per week in 2018 [5]. Oddo et al. [6] also revealed that the number of physical activities done by Indonesian adults has decreased over time. Whereas, most studies show that there is an increasing interest of people to do outdoor physical activities during stay-at-home policy implementation in several Indonesian cities [7], [8], [9], [10], [11]. Therefore, it is necessary to further investigate this phenomenon from the perspective of the urban planning field and confirm a theoretical proportion on the higher number of people done biking and walking during COVID-19 than before.

This study aims to analyse the pattern of people doing biking and walking before and during the COVID-19, using Sleman Regency, Yogyakarta as a case study. To achieve the objective, two research questions were raised: (1) What is the rate of the biking & walking activities before & during the COVID-19 pandemic? (2) What are the preferred routes and areas in doing biking and walking activities before and during the COVID-19 pandemic?

STRAVA METRO

This study used Strava metro’s datasets to capture all biking and walking data. Strava Metro is a web-based dashboard consisting of aggregated datasets to support data-driven bike and pedestrian planning which is processed based on geographic information system (GIS) environments [12] (see Figure 1). It can be accessed from the following website <https://metro.strava.com/>. This dashboard is developed by Strava, a mobile app-based social media for bikers, walkers, runners, and hikers. The app, depending on the user’s preference, can record each user’s activity when they use it. Then the data are processed by the Strava Metro team to be ready for use by the local government (either The Transportation Agency or the Planning Agency). Regarding data privacy, Strava has developed a data privacy policy that is based on European Union’s GDPR and the California Consumer Privacy Act (CCPA). Strava stated clearly in their privacy policy that they are permitted to use, sell, license, or share aggregated data to a third party, see [13]. However, Strava Metro excludes activities that have been made private by the users and deleted accounts. The aggregated data consists of user’s activity related to equipment, usage, demographics, routes, and performance.



Figure 1. Screenshot of Strava Metro Dashboard

The author accessed and retrieved datasets from Strava Metro based on collaboration with personnel from the Transportation Agency, Special District of Yogyakarta, Indonesia, as Strava Metro only permits local officials to access their data as a third party. The dashboard consists of two main menus, namely data and map. The data menu shows graphs and diagrams that summarise different types of aggregated data, such as demographics, tourism, trips, and people (see Figure 1). The map menu shows different types of spatial datasets, such as streets, corridors, routes, and heatmap, in which each of them has a data attribute shown in the data menu (see Figure 2).

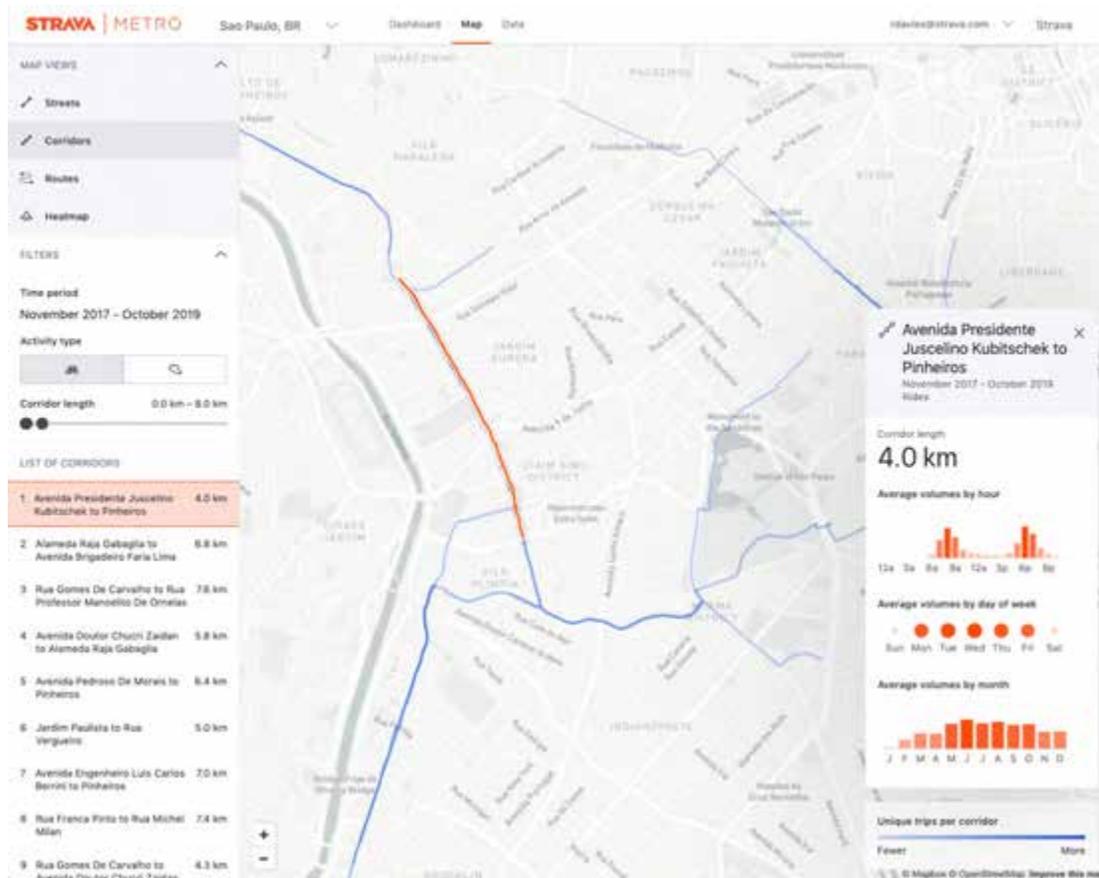


Figure 2. Screenshot of Strava Metro Map Menu
Source: [14]

The dashboard differentiates exercise activities into two types, namely biking and walking, running, hiking. Therefore, it has to be noted that the walking activity in this study also refers to running and hiking activities because these activities cannot be separated within the dashboard. Strava Metro users can download data from the map menu by choosing the type of exercise and period of activity. There are two types of downloaded data, namely .csv file (comma-separated values file format that can be opened through software like Microsoft Excel) and .shp file (shapefile format that can be opened through GIS software, like QGIS or ArcGIS). The .csv file consists of 33 data categories (see Table 1), whereas the .shp file consists of edges (polyline features) that visualise the streets having “edge_uid” for each section that has the same id number as in the .csv file. This study only uses data within the “trip” category because it counts all number of trips done by users without necessarily knowing how many numbers of people conducted the activity. Hence, it seems more reliable and less biased, as this study focuses more on the usage and pattern of biking and walking activities, not the number of people. It also merged the “forward” and “reverse” data of “trip_count” to accumulate and generalise all trips in each street.

Table 1. Data Categories of Strava Metro Datasets

| No | Data | Definition | Category |
|----|----------------------------------|--|-------------------------|
| 1 | edge_uid | Id number for each street block | Identifier number |
| 2 | activity_type | The type of exercise activity (bike or walking, running, hiking) | Activity type |
| 3 | hour/date/month/year | Aggregated timeframe | Timeframe |
| 4 | forward_trip_count | The number of bike or pedestrian trips on a particular edge during the given timeframe | Trip |
| 5 | reverse_trip_count | | |
| 6 | forward_people_count | The number of users who completed a bike or pedestrian trip on a particular edge during the given timeframe. For instance, 10 people may have completed 30 trips on an edge during the timeframe | People |
| 7 | reverse_people_count | | |
| 8 | forward_commute_trip_count | The number of users who frequently make the same trip during the timeframe | Commuter |
| 9 | reverse_commute_trip_count | | |
| 10 | forward_leisure_trip_count | The number of users who make the trip as a leisure activity during the timeframe | Leisure |
| 11 | reverse_leisure_trip_count | | |
| 12 | forward_morning_trip_count | The number of users who completed a bike or pedestrian trip on a particular edge in the morning or evening | Time-based trip |
| 13 | reverse_morning_trip_count | | |
| 14 | forward_evening_trip_count | | |
| 15 | reverse_evening_trip_count | | |
| 16 | forward_male_people_count | The number of users who completed a bike or pedestrian trip on a particular edge based on their gender | People counts by Gender |
| 17 | reverse_male_people_count | | |
| 18 | forward_female_people_count | | |
| 19 | reverse_female_people_count | | |
| 20 | forward_unspecified_people_count | | |
| 21 | reverse_unspecified_people_count | | |
| 22 | forward_13_19_people_count | The number of users who completed a bike or pedestrian trip on a particular edge based on their age | People counts by age |
| 23 | reverse_13_19_people_count | | |
| 24 | forward_20_34_people_count | | |
| 25 | reverse_20_34_people_count | | |
| 26 | forward_35_54_people_count | | |
| 27 | reverse_35_54_people_count | | |
| 28 | forward_55_64_people_count | | |
| 29 | reverse_55_64_people_count | | |
| 30 | forward_65_plus_people_count | | |
| 31 | reverse_65_plus_people_count | | |
| 32 | forward_average_speed | The number of users who completed a bike or pedestrian trip on a particular edge based on their speed | Average speed |
| 33 | reverse_average_speed | | |

Remark

Forward: trips traveling in the direction the street was digitized into Open Street Map (from the first point of the line to the last point of the line)

Reverse: trips traveling in the opposite direction the street was digitized into Open Street Map (does not indicate wrong-way travel)

Source: adapted from [15]

METHOD

This study used a spatial analysis approach to investigate the pattern of biking and walking activities by using Microsoft Excel and QGIS. The timeframe used in this study is from January 2019 to December 2020 which represents the situation before and during the COVID-19 pandemic. In Metro Strava, the user is only able to download the data each year for each type of activity. Therefore, there are four downloaded datasets (.csv and .shp) from the Metro Strava for this study, namely biking activity in 2019, walking activity in 2019, biking activity in 2020, and walking activity in 2020. From the .csv data, this study gathered 62,097 bike and 42,435 walk datasets in total (for the detailed amount of data in each year, see Figure 3). Each dataset indicates routes that are used by the Strava users during 2019 and 2020. It does not indicate the total trips of either biking or walking activities. From the .shp data, this study gathered 66,615 edges data (spatial polyline features) for both bikes and walk trips.

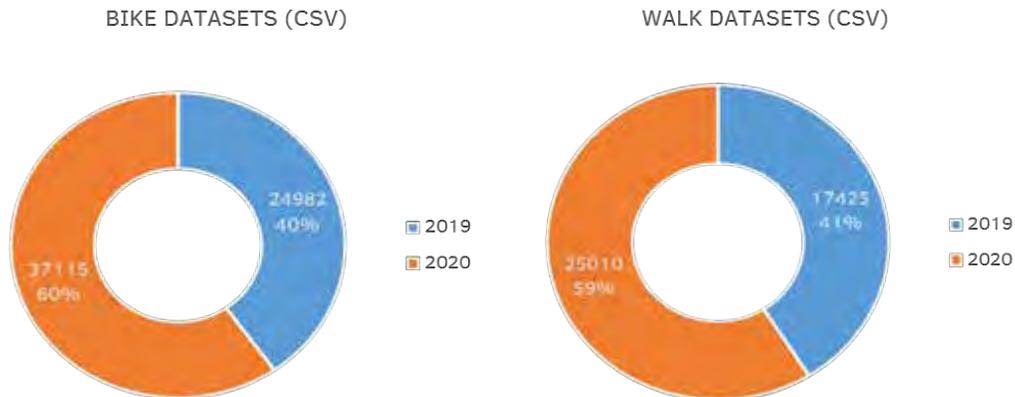


Figure 3. Total of Bike and Walk Datasets in 2019 and 2020

Regarding the analysis phase of the data, first, data from the .csv file was opened in Microsoft Excel to be cleaned (convert the comma-separated datasets into the column). Then the author only extracted data from the following category: identifier number, activity type, timeframe, and trip. Second, data from the .shp file was opened in QGIS to be checked whether it has the “edge_uid” or not in its attribute table. Third, the cleaned .csv file was imported to QGIS and merged with the attribute table of the .shp file. This action allows each edge of the polyline features to have their value based on the activity during the timeframe. Because of the “edge_uid” (identifier number), the attribute table was merged correctly. Fourth, the merged values on the attribute table within the .shp file were then converted into “integer” (number) format to allow the values to be calculated, normalised, and weighted. Fifth, the “trip” values were normalised into a 0-1 scale to make the data more consistent and reduce data redundancy. Sixth, the polyline was interpolated into point features with a 20 metres distance for each section. This action aimed to allow the normalised “trip” values to be visualised in a heatmap style so that the pattern of activity can be easily revealed. Seventh, the point features were visualised in a heatmap style given in the QGIS by using the normalised “trip” values as the main weight for the heatmap visualisation. Finally, there are four heatmaps (bike activity in 2019, walking activity in 2019, bike activity in 2020, and walking activity in 2020) that show the pattern of activity in each year and can be compared.

To support the spatial comparison, numerical data from the .csv file were calculated to understand the increasing or decreasing number of bike and walking activities between 2019 and 2020. The analysis result was interpreted in two ways. First, the spatial analysis result is interpreted by comparing the two maps in each activity and conclude which area is the most favourable. Second, the calculation of numerical data was described based on the rate of activities between 2019 and 2020.

RESULT AND DISCUSSION

The Rate of Bike and Walk Trips

The rate of bike and walk trips are calculated by summing all trips made in every route within the area of Sleman Regency, Yogyakarta during 2019 and 2020. Regarding the bike trips, there are 73,416,115 bike trips in total which can be divided into 16,307,415 trips in 2019 and 57,108,700 trips in 2020 (see Figure 4 for the rate of trips). Figure 4 reveals there is an increase of up to 56% in bike trips during the COVID-19 pandemic. Therefore, it confirms the direct observation and studies that suggested there is increasing motivation and interest of people in doing biking activities, in this case, in Sleman Regency, Yogyakarta area. This result is also in line with trends in other countries, where there is a higher number of biking activities during stay-at-home policy implementation (see [16], [17]). Buehler and Pucher [18] supported this argument that in most cities in the US, Europe, and Australia, there was an enormous increase in biking activities during the pandemic which can be a window of opportunity for the government to reflect and improve their biking-related infrastructures and programs. In the Indonesian context, Budi et al. [19] found that there are five factors that driven people to do more biking activities during stay-at-home policy implementation, namely health (increasing immune strength and body fitness), environment (better air quality outside due to the decreasing of vehicle use during a pandemic), media (social media influence that grows the biking trend), and lifestyle (people tend to follow the common trend and show off their social status based on their type of bike).



Figure 4. Bike Trips Rate Before and During COVID-19 Pandemic

Regarding the walk trips, there are 5,733,995 walk trips in total which can be divided into 1,993,520 trips in 2019 and 3,740,475 trips in 2020 (see Figure 5 for the rate of trips). Figure 5 reveals there is an increase of up to 30% in walk trips during the COVID-19 pandemic. Therefore, it also confirms the direct observation and studies that suggested there is increasing motivation and interest of people in doing walking activities, in this case, in Sleman Regency, Yogyakarta area. It has to be noted that this study refers to walking activities based on the Strava data category, in which walking is also includes running and hiking activities (both recreational and serious exercise). In this sense, the result of this study is in line with trends in other countries, where there is a higher number of walking activities during stay-at-home policy implementation (see [20], [21], [22]). However, if “walking” is referred to the walking activity in daily life (go from one point to a destination for a specific purpose), several studies suggested that there is a decrease in walking steps during the COVID-19 pandemic (see for instance [23], [24]). This makes sense because most people use the Strava app to do an exercise (either for recreational or professional purposes).



Figure 5. Walk Trips Rate Before and During COVID-19 Pandemic

Comparing between bike and walk trips rate, it is clearly shown that biking is more favourable than walking before and during the COVID-19 pandemic. It is revealed from the comparison of a total number of trips between biking and walking activities (see Figure 6). Figure 6 shows the higher rate of the bike than walk trips both in 2019 and 2020. In 2019, the rate of bike trips is 78% higher than walk trips. While, in 2020, the bike trips are 88% higher than walk trips. Therefore, biking activities are significant before and during the COVID-19 pandemic.

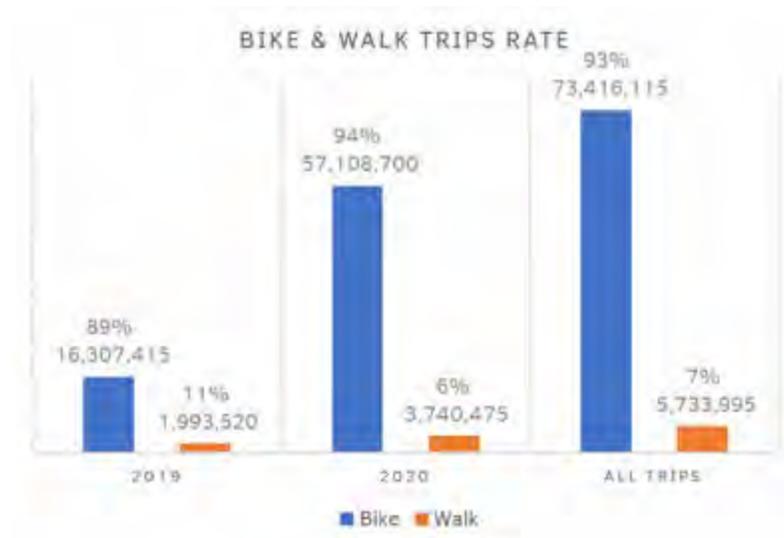


Figure 6. The Comparison of the Bike and Walk Trips Rate Before and During COVID-19 Pandemic

The Preferred Routes of Bike and Walk Trips

The preferred routes of bikers and walkers were identified by visualising the heatmap of bike and walk trips weighted by the normalise the number of trips that occurred in each street. Regarding the bike routes, the distribution pattern mostly remains the same between trips in 2019 and 2020 (see Figure 7). However, several spots have higher density during the pandemic. Figure 7 shows the distribution of bike trips during the pandemic was concentrated more on recreational areas (in the north, south, and east of the area). In the north, bikers seem to enjoy their ride in the area of a local university and nearby local favourite restaurants. In the south, they seem to go either to the centre of Yogyakarta City or to the sub-urban area of Sleman Regency to enjoy several recreational spots. This interpretation comes up because the data is summed between forward and reverse trips. In the east, bikers seem to enjoy *Prambanan* Temple because it is the most common recreational destination for people in the Yogyakarta area. Besides the recreational area, the newcomers (bikers who are active during the pandemic) seem to make more rides in the sub-urban area of Sleman Regency, such as in the west and north-east area where the heatmap shows thicker colour. It reveals that during the pandemic, bikers seem to prefer a quieter route to either go or just pass by several recreational spots in Sleman Regency and around the Yogyakarta area.

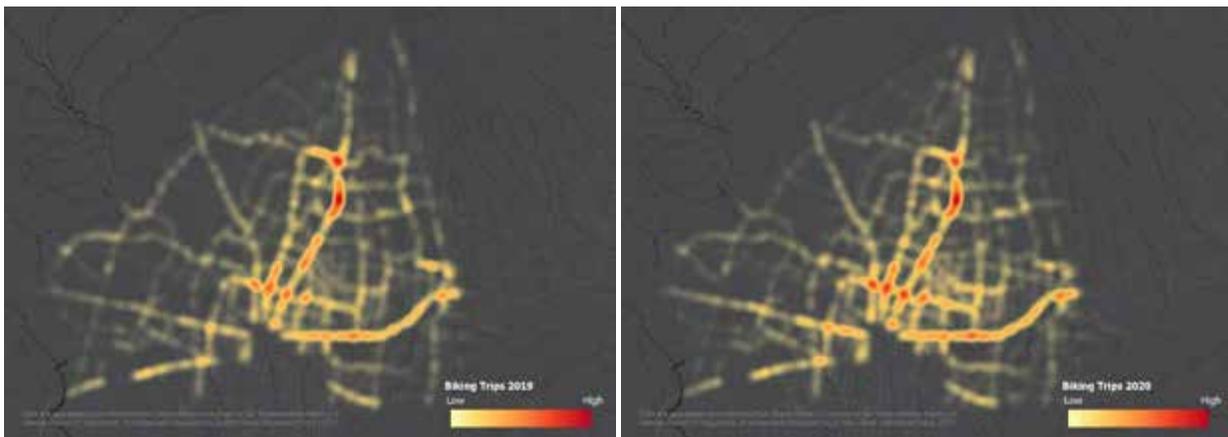


Figure 7. The Comparison of Bike Trip Routes Distribution Before (right) and During (left) COVID-19

Regarding the walk routes, there is a significant expansion in the distribution of walk areas between trips in 2019 and 2020 (see Figure 8). Figure 8 shows the distribution of walk trips during the pandemic expanded almost in every direction of the Regency. There are two spots with the highest rate of walk activity which show that most walkers prefer to enjoy their walk activity in a recreational area (an area of local university, located in the south, and a local reservoir park, located in the east). Besides the recreational area, the newcomers (walkers who are active during the pandemic) seem to be more active in both urban (in the south), peri-urban (in the middle), and sub-urban areas (in the north, west, and east) of Sleman Regency. It reveals that during the pandemic, people seem to be more motivated to do walking and running activities. Walkers (including runners) seem to prefer to have their activity in the recreational area, in which several of them tend to explore random streets in Sleman Regency.

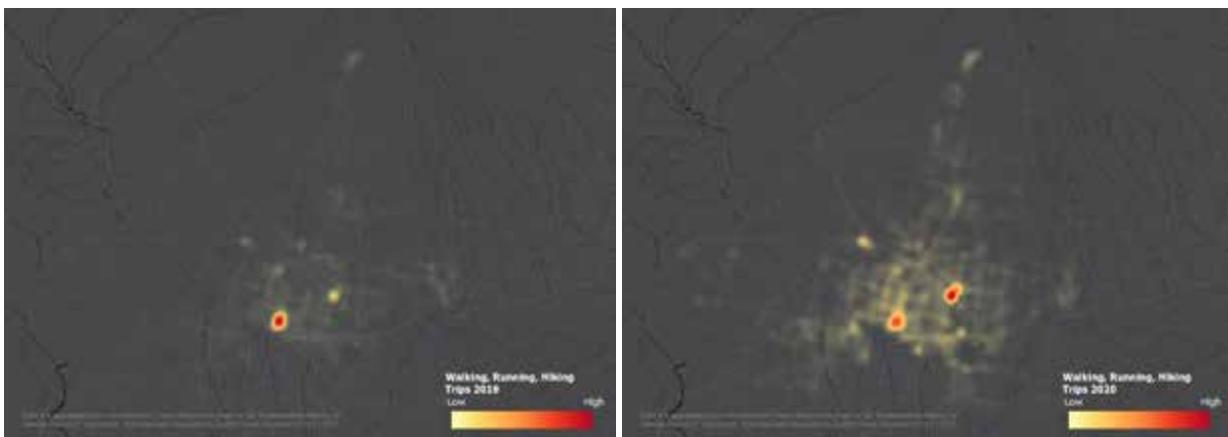


Figure 8. The Comparison of Walk Trip Routes Distribution Before (right) and During (left) COVID-19

The result shows both biking and walking activities have occurred in either urban, peri-urban, or suburban streets. It contradicts with the condition in the field, in which most of the streets in Sleman Regency have no bike lanes and there are fewer pedestrians across the area, especially in peri-urban and suburban areas. The authority should be aware of this issue to make biking and walking activities sustain not only during the pandemic but also in the post-pandemic. As have been addressed by several studies, the local government needs to be aware of the increasing trends of biking and walking activities during this pandemic to provide adequate, safe, and integrated biking and walking infrastructure (i.e. bike lanes and pedestrians) so that this momentum can be utilised to make a more sustainable, healthy, and greener urban area ([18], [25], [26]). Furthermore, NACTO [27] suggested several improvements on urban streets to adapt to the pandemic and post-pandemic situations, such as pedestrian widening and dedicated bike lanes with clear signage and safe infrastructure across the desired area. Other studies also suggest the need for urban planners to rethink the biking and walking space in the post-pandemic city, in which planners should innovate and pursue more green-oriented planning to both decrease the COVID-19 spreading and encourage more biking and walking cultures [28], [29].

However, in the Indonesian context, both the government and urban planners, especially in the Yogyakarta area, should be aware of several factors affecting the comfortability of bikers and walkers. As Anurogo et al. [31] and Hidayat and Widartono [31] stated that from several factors affecting the comfortability of bikers and walkers, five factors are the most influencing bikers' and walkers' comfortability, namely topography, traffic density, side obstacles, and vegetation canopy availability. Therefore, planners should have innovative solutions to cope with the comfortability factors for Indonesian bikers and walkers, not only imitating design from western cities. One innovative approach that can be used by planners is to plan based on user-generated data through social media platforms, like Strava, to either reveal alternative insights that are not covered by official statistical data or complement the official statistical data (see [32]). The user-generated data can be analysed by using spatial analysis to provide clearer insights into the current situation in every area of the city (see [33], [34]).

CONCLUSION

This study aimed at analysing the pattern of biking and walking before and during the COVID-19, using Sleman Regency, using Sleman Regency, Yogyakarta as a case study. It reveals the rate of biking and walking activity and the preferred routes and areas before and during the COVID-19 pandemic. Regarding the rate of biking, it is shown that there is an increase of up to 56% in bike trips during the COVID-19 pandemic which were influenced by five factors, namely health, media, and lifestyle. This can be a window of opportunity for the government to reflect and improve their biking-related infrastructures and programs. Regarding the rate of walking, it is shown that there is an increase of up to 30% in walk trips during the COVID-19 pandemic in which it referred to walking and running as exercise (either for recreational or professional purposes). Also, from all years, bike trips are higher than walk trips (86% higher). Therefore, this study confirms the increased trend of doing biking & walking activities during the pandemic in Sleman Regency, Yogyakarta. It shows that the stay-at-home policy drives people to do more outdoor activities.

Regarding the preferred routes and area of bikers, it is revealed that the distribution of bike trips during the pandemic was concentrated more on recreational areas (in the north, south, and east of the area) and the sub-urban area (such as in the west and north-east of the area). Bikers seem to prefer a quieter route to either go or just pass by several recreational spots in Sleman Regency and around the Yogyakarta area. Regarding the preferred routes and area of walkers, it is revealed that the distribution of walk trips during the pandemic expanded almost in every direction of the Regency. Most walkers prefer to enjoy their walking activity in the recreational area and both urban (in the south), peri-urban (in the middle), and sub-urban areas (in the north, west, and east) of Sleman Regency. People seem to be more motivated to do walking and running activities in the recreational area, in which several of them tend to explore random streets in Sleman Regency.

The government should maintain this moment to transform their city into a more sustainable area in the post-pandemic situation. Also, planners should be aware of this phenomenon to provide the needs of bikers, walkers, & runners both in the urban, peri-urban, sub-urban, & rural areas. The user-generated data can act as an alternative and complementary method in the urban planning process. Future researches can investigate the method to accurately calculate the data bias of user-generated data that will be used in planning and further analyse Strava data, especially by using the demographic, temporal, and performance data.

ACKNOWLEDGEMENT

The author would like to acknowledge Mr. Yorri K. Nugraha from the Transportation Agency of Daerah Istimewa Yogyakarta (DIY) who applied for the Strava Metro dashboard access on behalf of the Agency, retrieved raw data from the dashboard, and provide it to the author. The Agency supported the author to do this study as the data provider and not as a collaborating partner.

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PROPOSAL OF AN INTEGRATED ECOSYSTEM URBAN INDEX FOR THE URBAN PROJECTS EVALUATION IN ECOSYSTEMIC KEY

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ABSTRACT

The complex structure of cities requires actions aimed at urban sustainable principles. According to current international and European planning dispositions on sustainable development, there is shared interest in programming-planning objectives of interventions to promote territorial growth in view of intergenerational equity. The actual epidemic emergency and its impact on the existing socio-economic, productive and environmental assets have emphasized the need to act in view to ensuring uniformity between territorial portions through services and goods. So to mitigate the corresponding trade-offs in terms of the citizen's needs.

The valorization and preservation of existing built-natural environment capable of generating eco-systemic services is a strategic asset for many European and non-European cities. To support initiatives planning according to sustainable criteria, this contribution proposes a synthetic index, the Composite Economic- Environmental Index (CEEI), as incentive for public and/or private subjects to express convenience judgements on urban renewal projects as well as to identify priority intervention areas from an eco-systemic point of view. The construction of IEU indexes is conducted through a multi-parameter methodological approach (Integrated Assessment Framework, IAF). The proposed IAF is characterized by logical- operational phases that lead to the definition of the proposed index. Some of them are by the implementation of algebraic structures typical of the Benefit of Doubt Approach and of Goal programming.

KEYWORDS

Nature-inclusive design & planning; Ecosystem services; Decision-making systems;
Multicriteria analysis; Optimization algorithms

INTRODUCTION

Environmental advocates and proponents of economic growth are increasingly at odds. This having looked at the economic impact of the environment decline as well as the environmental loss that occurs with unchecked growth and urbanization.

Many studies shown the human impact on the environment is consistent [1,2]. According to Goudie (2020), the main researchers interest in the area of environmental change can be defined in the following dimensions: clearing of woodland, domestication process, draining of marshlands, introduction of alien plants/animals, landscape change [1].

Human settlement in the context of the environment highlights the role people play. The definition of factors causing climate change, characterization of the urban process, linkages between technology and sustainable development, drives of economic dynamism will be crucial for the next decades [3].

By COVID-19 the world shook in its foundations, as the global lockdown touched not only the world-wide economy but also society and the environment. Nicholas Bloom (2009) has looked at past shocks and how they have impacted economies as well as for how long. Julie Thomas (2002) evaluated the underlying economic factors that make a shock more damaging to certain economies or industries. Understanding these vulnerabilities will help recover from economic shocks, and it allow to better understand how impacts on individual businesses can be implemented. The pandemic revealed the need to adopt a global development approach, considering four dimensions: global value chains, debt, digitalization, and climate change [4]. By way, the European Economic Recovery Plan Next-Generation EU 2020 urges Member States to support the European Green Deal and digitalization that will boost jobs and growth, the resilience of our societies and the health of environment. This not only by supporting the recovery, but also by investing in the more sustainable, digital, social, resilient development of Europe.

The pandemic crisis changed how the various components of globalization work together; understanding these changes will lead national economies to innovate and reach new trajectories [5]. According to the World Investment Report 2020, the discussion will focus on reshoring diversification, regionalization, and replication. The report underlines that the future will bring change in the development and global order. The world economy will move from the Global Value Chains to Sustainable Development Goals.

In this perspective, the human-nature relation will be crucial to evaluate the impact of COVID-19. The crisis resulting from the pandemic profoundly influenced individual behavior, and it is necessary to look at these changes from the social, behavioral, environmental, economic perspective [6]. The challenges people face during this time are many, some examples being the digitalization of society, remote work, and the shift in consumer behavior [7]. In the context of digitalization, on the one hand, remote work decreased the negative impact on the economy in many sectors, including the employment sector [4]; on the other hand, there is a threat of marginalization of selected social groups as a result of unequal access to information and communication technology (ICT) infrastructure and devices. However, the outbreak of the pandemic revealed the existing division on the national and international levels. The most disadvantaged persons may become further marginalized since they lack access to devices, infrastructure, and know-how [8,9].

At the same time, the experts at the World Economic Forum predict that the world will observe the reverse trend of urbanization, which undoubtedly will bring positive results for the environment [10]. The discussion may focus on the possible scenario of city shrinkage [11].

By it a discussion on the impact of the COVID-19 outbreak may be conducted in three main dimensions in the context of sustainable development: ecological, social, and economic. However, there is a horizontal aspect that makes an impact on these layers: policy management. The effectiveness of policy management, especially in urban context, will be a crucial point in the recovery from the post-pandemic slowdown.

WORK AIMS

The current contribution deals with the construction of an evaluation protocol which, based on a theoretical and methodological framework, represents a guide for private and public subjects to assess the economic and environmental sustainability level of urban transformation projects at different spatial scales as identified in the Leipzig charter: neighborhood level, local authorities/municipal level, functional areas.

The theoretical and methodological framework proposed is based consists of the following main steps:

- i. data collection of the spatial structure of the urban plot *ex-ante* transformation project;
- ii. assessment of impacts (of economic, social and environmental type) in the surrounding intervention area *ex-post* project;
- iii. implementation of the Benefit-of-the-doubt (Bod) approach for the construction of the Composite Environmental Indicator (CEI);
- iv. benchmark weighting factors for CEI;
- v. definition of the Composite Environmental-Economic Indicator (CEEI) for *i-th* urban action.

The relationship between spatial planning and urban system with environmental-socio-economic feature of the context for CEEI definition is in terms of ecosystem services supply-demand.

Tools are proposed to support the rollout of theoretical framework for CEEI. The BoD approach is applied to determine the CEEI by setting the related optimal benchmark through a goal programming algorithm. The mathematical programming environment for writing the regression system can be A Mathematical Programming Language (AMPL). It is a simple and intuitive tool used for structuring mathematical programming problems. Resolutions of goal programming algorithms can be through proper solvers, like CPLEX, FortMP, MINOS and KNITRO.

By the CEEI public and private subject can be able to: *i*) identify the most sustainable alternative of investment; *ii*) improve the portfolio-selection projects; *iii*) spending public and private financial resources on urban projects according to sustainability features as required in world policy documents at European- global frame.

MATERIALS AND METHOD

In order to detect the logical-functional dependencies between study variables representative urban system with ecosystem services supply by land-use typology a multi-parametric optimization analysis is proposed. This to identify the relationships between parameters of multi-layer affiliation, and to establish a flow for an environmental and economic composite indicator definition to use in evaluation process for city planning green-safe.

The proposed evaluation protocol consists of the following steps:

1. Data collection *ex-ante* intervention on urban plot area (1.1), and assessment of eco-systemic qualitative impacts in the area of intervention *ex-post* renewal project (1.2);
2. Implementation of the BoD approach for CEI construction;
3. Optimal benchmark weighting with Goal Programming Model;
4. Layout of the expression for CEEI.

The Fig. 1 illustrates the methodological framework proposed. Subsequently each part of evaluation protocol pro-posed is described.



Figure 1. Methodological framework for the definition of an assessment composite indicator.

Step 1.1 Data collection *ex-ante* intervention on urban area

To define an evaluation index under environmental-economic point of view according to the socio-economic and environmental features, the data set is constructed with the values of the variables considered: land use and eco-system services. This *ex-ante* implementation of the project.

The values of the variables can be collected using different information systems geo-referenced and not. Among these, e.g. not exhaustive, the best well-known are: i-Tree Landscape Tool that gives information on tree cover, land use and basic demographic characteristics of the census areas in United States of America; Urban Atlas provides pan-European comparable land cover and land use data for Functional Urban Areas. These are mainly geo-referenced information layers that give information on social, economic and environmental features. In relation to each land use type ecosystem services are estimated. This through specific performance indicators.

Since the beginning of the last century, Night-time light data have also been used for economic, social and environmental analysis. With reference to economic studies, night lights can provide indications of a territory's productivity level [12]. Doll et al. (2006) analyse the night images of eleven European cities showing the significant interdependence between the amount of lights and the corresponding nominal GDP [13]. Sutton et al. (2007) also came to the same conclusion, taking several cities in the United States, India, China, and Turkey and comparing the corresponding GDP values with each city's light levels [14]. Other economic applications include surveys to establish the level of correlation between night light intensity and the city's Community Housing Prices (CHP). Such experiments are conducted by Chang Li et al. (2019) in the city of Whuan (China). The study by Chang Li et al. demonstrates the existence of correlation between Night-time light data and Community Housing Prices [15].

In addition to being a variable proxy for the level of wealth of the territory, light emission can provide important information on human settlements. Sutton (1997) demonstrates the interdependence between number of lights and population density [16]. This is done by comparing population data from the American census with satellite images of night lights in some cities. The Gridded Population of the World (GPW), i.e. the database on global population density most used for the development of analyses on world population growth, is built using Night-time light data as a proxy variable of the housing capacity of a territory. Other applications of night light emissions relate to the mapping and measurement of urban boundaries within which cities develop [18]. Imhoff et al. (1997) study the correlation between night-time light data and urban growth [19]. Finally, the lights at night are also linked to the different energy consumption of cities. Elvidge et al. (2011) show that there is a significant correlation between night lighting with energy consumption in some American cities [20]. Similar studies are conducted in India [21], Brazil [22] and Japan [23].

The information on land use type qualifies the survey area according to its capacity to produce goods and services to the community. In addition, it allows to estimate the trade-off between *ex-ante* and *ex-post* urban project implementation in terms of impacts on the ecosystem services production by the land use changes.

Step 1.2 Assessment of eco-systemic impacts *ex-post* urban project

The classification of the intervention area in terms of land use and capacity to implement ecosystem services in the reference context is preliminary to the estimation the impact of the project. In order to quantitatively assess the effects of the project on ecosystem, multi-criteria evaluation methods and techniques based on operational tools currently in use can be implemented. Among these, for example, it is notable the Natural Capital Planning Tool (NCPT). It is an assessment tool developed specifically for the planning context. The NCPT allows the indicative but systematic assessment of the likely impact of proposed plans and developments on Natural Capital and the ecosystem services it provides to people such as recreational opportunities, air quality regulation and climate regulation. The NCPT was designed as a fit-for-purpose Excel tool which can be applied by non-specialists, and in a short period of time; acknowledging the time, resource constrains planners and developers face in everyday practice. NCPT helps planners to create more sustainable places for people and wildlife, whilst at the same time delivering the housing and infrastructure the country needs.

With the use, e.g. of NCPT, trade-off in terms of impact (*I*) on the ecosystem services production regarding specific intervention features plat are estimated. The *I* values are on the basis of environmental-economic indicators.

Step 2. Implementation of the BoD approach for the construction of the Composite Indicator

The construction of the environmental-economic indicator to support the evaluation of urban initiatives in ecosystemic key will take place by implementing multicriteria/multi-objective techniques with the help of goal programming algorithms and advanced techniques for the management and big data use, such as the BoD approach, in charge of a composite indicator definition.

The need to solve complex decision-making processes, characterized by high uncertainties and conflicting goals, has led to the identification of goal programming as one of the most widely used multi-criteria decision-making techniques most of all – but not limited to – within the issues of: environmental, financial, social and political assessment [24-27]

The DEA employs linear programming tools to estimate an efficiency frontier that would be used as a benchmark to measure the relative performance of unit elements of different type. This requires construction of a benchmark (the frontier), and the measurement of the distance between unit elements in a multi- dimensional framework. The application of DEA to the field of composite indicators is known as the BoD approach, and it was originally proposed to evaluate the macro-economic performance of specific territorial context. In the BoD approach, the Composite Environmental Indicator (CEI) is defined as the ratio of the actual performance to its benchmark reference:

$$CEI = \frac{\sum_{i=1}^M I_q \cdot w_q}{\sum_{i=1}^M I^* \cdot w_q}$$

where I_q is the normalized score of q_{th} individual indicator ($q=1, \dots, Q$) for project's performance p ($p = 1, \dots, M$), and w_q the corresponding weights. The last ones can be drawn on the basis of the matrix for the assessment of the different land cover types' capacities to provide selected ecosystem goods and services by Burkhard *et al.* [28].

Cherchye *et al.*, (2004) [60] suggested obtaining the benchmark as the solution of a maximization problem. I^* is the score of the hypothetical element unit (Project) that maximizes the overall performance (defined as the WeiGhTed average, WGT), given the (unknown) weights set (WGT) of i -th element w . The $CI_{environmental}$ value is in [0-1] range [29].

Step 3. Weighting

The w referred to I^* can be solved via the algorithms of Operational Research. These are capable of solving linear systems to maximize and/or minimize an objective function.

The AMPL software is used to structure the optimization model proposed. The model written in the AMPL programming environment is in Table 1.

Table 1. The model written in A Mathematical Programming Language (AMPL) software (.mod file).

| Model |
|--|
| <p>SETS</p> <p>set WGT;</p> <p>PARAMETERS</p> <p>param weights{WGT};</p> <p>param services{WGT};</p> <p>VARIABLES</p> <p>var x{i in WGT} >= 0;</p> |
| <p>OBJECTIVE FUNCTION</p> <p>maximize objective: sum{i in WGT} x[i]*services[i];</p> <p>CONSTRAINTS</p> <p>s.t.vinc_1: sum{i in WGT} x[i] >= 0;</p> <p>s.t.vinc_2: sum{i in WGT} x[i] - sum{i in WGT} weights[i] >= 0;</p> <p>s.t.vinc_3 {i in WGT}: x[i] - weights[1] >= 0;</p> <p>s.t.vinc_4: sum{i in WGT} x[i]*services[i] >= 0;</p> <p>s.t.vinc_5: {i in WGT}: (x[i]+1)*services[1] <= TARGET [i];</p> |

The analysis units (set WGT) are described according to three factors (set PARAMETERS): weights and services. The parameters weights are referred to the ordinary values w it is possible to define in corresponding of each ecosystem services type. They are found in the scientific reference literature.

The unknowns (x) are continuous. The objective function is: maximize objective: sum{i in WGT} x[i]*services[i];

The MINOS optimization program is used as a solver implementing algorithm for the linear problem considered in the respect of the CONSTRAINTS.

Step 4. Environmental-Economic Composite Indicator

A measure that summarizes the value of the contributions of nature to economic activity that summarizes the value of ecosystem services in a single monetary metric, called (CEEI), is proposed.

Sautton, P. and Costanza, R. (2002) express the level of urban economic productivity of an urban area by means of the Subtotal ecological-economic Product (SEP):

$$SEP = GDP + ES$$

i.e. the sum of GDP as the pressure on the level of economic productivity of a territory) and ES, or rather Ecosystem Services due to the existing and/or new natural component, as percentage of GDP value.

According to the (2), the composite environmental-economic indicator ($CEEI_{en}$) proposed is structured as follow:

$$CEEI = CEI \cdot GDP + GDP$$

where CEI is obtained by BoD approach in conjunction whit Goal Programming model implementation (see Table 1).

CONCLUSION

The valorization of the urban ecosystem must be one of the programmatic and planning priorities for the sustainable urban development. The use of economic valuation methods and tools is more necessary than ever to support the ecological transition in the city. This in response to the awareness of the scientific community, and others, of the beneficial effects (ecosystem services) produced by terrestrial and marine ecosystems on social, environmental and productive infrastructures.

Among the operational mechanisms available for the formulation of convenience judgments on ecosystem- based investments is the construction of composite indices. These are often used to express the economic- financial performance of investments in projects, for example, of urban renewal and/or the regeneration of urban ecosystems. Recently, they have also been used to measure the performance of projects with a view to the economic, environmental and social sustainability of the territory.

This contribution is aimed at proposing a multi-parameter evaluation procedure to help the construction of evaluation indexes of ecosystem performance of interventions in urban areas. The proposed frame-work is based on the implementation of serial evaluation methodologies of a theoretical-operational nature. These include also the use of geo-referenced information, such as the night lights, as proxy variables for the localized measurement of ecosystem services and the corresponding economic value. Also the appeal to the use of models of optimization for the computation of the weights to employ in the framework of the BoD represents operating strategy that allows the rigorous construction of the CEEI.

Investigation of alternative reference procedures for the construction of indices, such as the Choquelet integral, comparison of results from multiple computational procedures, application of the proposed framework to cases of urban redevelopment, as well as integration between the proposed framework and more commonly used economic-financial analyses, such as Cost-Benefit Analysis, represent research avenues to be pursued.

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A SUSTAINABLE DESIGN METHODOLOGY BASED ON HIERARCHICAL DESIGN BRIEFS

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ABSTRACT

Green building rating and assessment tools implicitly define 'ideal green or sustainable buildings' through the criteria they include. While these frameworks are often used to assess existing buildings and proposed designs there is limited research to show how these can be used to create new designs. The study presented in this paper explores how criteria from green and sustainable building assessment tools can be integrated into design processes. A hierarchical design methodology is developed which translates criteria found in green and sustainable building rating tools into structured design briefs which can be used to generate designs for elements such as building layouts, building form, building envelope, services, and internal layouts. The value of this methodology is tested by applying it to generate a conceptual design for an urban case site. The study finds that the methodology and its application provide valuable insight into how more sustainable designs can be developed and recommendations are made for its further development.

KEYWORDS

Green building rating tools; Sustainable Building Assessment Tools, Hierarchical design briefs; Sustainable Performance

INTRODUCTION

Designing sustainable buildings can appear to be a ‘hit-and-miss’ process. Design teams receive a brief from a client, design a building, and then get this built. During this process, a rating using a green building rating tool may be carried out. This rating confirms whether the design or completed building has met a set of defined criteria. Often, by the time ratings are applied the main features of a design have already been developed, and the rating does not influence this. Ratings, therefore, generally reflect the performance of already designed products and do not help generate their development. Instead of directly influencing early conceptual designs, rating tools capture the performance of completed designs. Rating tools thus appear to be designed to *monitor* the development of green buildings rather than *generate* this [1]. In this process there is the danger that sustainability performance becomes an arbitrary byproduct rather than the driving force for a design. This paper explores whether, and how, rating tools can be used to generate more sustainable designs instead of just monitoring their development.

There has been huge growth in green building rating tools and Doan *et al.*, estimates that there now over 600 different types of tools internationally [2]. BREEAM, the oldest rating tool has been used to certify over 560,000 buildings and the LEED rating tool has been used in over 160 countries [2]. Despite their success, there has been enduring criticisms of these tools by researchers. Rees (1999), Kohler (1999), Cooper (1999), Runde (2010) and Berardi, (2013) argue that that rating tools do not address sustainability sufficiently [3, 4, 5, 6]. Ali and Al Nsairat (2009) state that green building rating tools tend to focus on standard environmental criteria and do not respond to the local context or include issues such as culture and practice [7]. Krizmane, et al., (2016) indicate that rating tools need to have a stronger focus on sustainable development and address issues such as human rights, poverty reduction, job creation, economic growth, energy security and public health [8]. Cooper (1999) argues that rating tools are insufficiently rigorous as criteria assess performance against relative rather than absolute targets and therefore their achievement may not result in the building making a sufficient contribution to sustainability at a global scale [5]. Ameen, et al., 2015; Rees, 1999; Cooper, 1999 also criticize rating tools for avoiding difficult, but necessary requirements, to include criteria that promote resource caps and more equitable access to services and products [9, 3, 5].

Green rating tools such as LEED and BREEAM have become complex, require large amounts of data, and take a significant amount of time to complete [10]. Rating tools also often rely on specialist commercial products such as energy simulation software and expertise, which can be expensive. These costs can inhibit the use of ratings in buildings and therefore limit the extent to which they influence designs. Where ratings are targeted in designs, the additional costs of required assessments and modelling may restrict their application and the extent to which innovation and iterative design is pursued.

The cost and specialization required for ratings often results in a consultant being appointed who then is responsible for ‘managing’ sustainability. This can lead to designers abnegating their responsibility for sustainable design to the consultant, leading to poor designs. This approach may also result in ‘point-chasing’, where items are included in a building even if they are not necessary because of the need for additional low cost, or ‘easy-to-achieve’ points to achieve a rating.

Rating tools with highly defined protocols and fixed criteria may also entrench inertia and discourage rigorous investigation and more responsive approaches. Studies by Lynch and Mosbah (2017) confirm the importance of undertaking local investigations and studies to ensure that proposals relate directly to local issues and goals, rather than relying on metrics developed by others [11]. Repeated use of static metrics, they suggest, lead to gaps and crucial local sustainability issues sometimes being overlooked.

Research carried out by the RIBA indicates that simple practice-based checklists are more likely to be used by design teams working under pressure [10]. These checklists enable priorities and targets to be rapidly set and then tracked in design development. As a working tool, checklists can be developed to align with the way the design teams work. For instance, checklists may be broken down to reflect hierarchical design decision, design disciplines and design stages of work.

The study presented in this paper explores how sustainability can be a key generator of design. A methodology is developed to translate sustainability criteria found in green and sustainable building rating tools into hierarchical structured design briefs. These briefs can be used to develop designs which effectively integrate sustainability. The value of this approach is tested through a case study in which criteria from a sustainable building assessment tool are used to generate structured design briefs which are then applied to an urban site. The study addresses the following questions:

- How can design briefs be developed from green and sustainable building design tools?
- How can briefs developed in this way be applied to develop designs?
- Do designs developed in this way appear to support high sustainability performance?
- Does this approach offer value and insight into how design processes could be improved?

METHODOLOGY

To answer these questions the following steps are undertaken. First, a sustainable building assessment tool is selected and presented. Second, the selected tool is analyzed to develop structured design briefs. Third, these briefs are applied to a case study site to generate proposed designs. Fourth, the resulting designs are assessed in terms of sustainability performance. Fifth, results and the process are critically reviewed. Sixth, conclusions and recommendations are drawn.

This study follows an exploratory research approach. This is appropriate to early-stage research where methodologies have not been fully developed or tested [12]. It is suitable for work that investigates new areas and aims to develop and test different approaches [12]. The exploratory research carried out in this study aims to develop and test a methodology for developing more sustainability designs using criteria from green and sustainable building rating tools [13]. The study aims to contribute to knowledge on how high-performance sustainable buildings can be designed more effectively and efficiently [13].

THE SUSTAINABLE BUILDING ASSESSMENT TOOL

The Sustainable Building Assessment Tool (SBAT) was developed in South Africa and has an emphasis on developing country contexts. Sustainability assessments are carried out by defining and measuring performance in terms of sustainability objectives. The achievement of sustainability objectives is measured by the extent to which a design of a building achieves defined criteria [14]. Performance areas, sustainability objectives and criteria are shown in Table 1.

Table 1. Sustainable Building Assessment Tool Categories, Areas, Objectives, and Indicators [14].

| Area | Objective | Criteria |
|-----------------------|--|---|
| Energy | Built environment is energy efficient and uses renewable energy | EN1 Orientation, EN2 Building Depth, EN3 Roof Construction, EN4 Wall Construction, EN5 Floor Construction, EN6 Window to Wall Ratio, EN7 Ventilation openings, EN8 Daylight, EN9 Internal Lighting, EN10 External Lighting, EN11 Installed Equipment Power Density, EN12 Food Cooking, EN13 Water Heating, EN14 Renewable Energy Generation |
| Water | Built environment minimizes the consumption of mains potable water | WA1 Toilets, WA2 Wash Hand Basins, WA4 Showers, WA5 Hot Water, WA6 Landscape, WA7 Rainwater harvesting |
| Waste | The building minimizes emissions and waste directed to landfill. | WE1 Recycling Area, WE2 Recycling Collection, WE3 Organic Waste, WE4 Sewage, WE5 Construction Waste |
| Materials | Construction impacts of building materials are minimized. | MA1 Building Reuse, MA2 Timber Doors and Windows, MA3 Timber Structure, MA4 Refrigerants, MA5 Volatile Organic Compounds, MA6 Formaldehyde, MA7 Locally Sourced Materials |
| Biodiversity | Built environment supports biodiversity | BI1 Brownfield Site, BI4 Municipal Boundary, BI3 Vegetation BI4 Ecosystems |
| Transport | Built environment supports energy efficient transportation. | TR1 Pedestrian Routes, TR3 Cycling, TR3 Public Transport |
| Resources | Built environment makes efficient use of resources. | RE1 Site Density, RE2 Area per occupant RE3, Renewable Energy Generation, RE4 Food Production |
| Management | Built environment is managed to support sustainability. | MN1 Manual, MN2 Energy Metering, MN3 Water Metering, MN4 Recording, MN5 Residents Association |
| Local Economy | Built environment supports the local economy. | LE1 Locally Sourced Materials and Products, LE2 Small Enterprise, LE3 Construction Workers Support |
| Services and Products | Built environment supports use sustainable products and services. | SP1 Fruit and Vegetables, SP2 Bakery Products, SP3 Beans and pulses, SP4 Milk and Eggs, SP5 Clothing, SP6 Furniture, SP7 Equipment Hire, SP8 Notice Board |

| | | |
|-----------------|---|---|
| Access | Built environment supports access to facilities. | AC1 Internet Access, AC2 Banking, AC3 Groceries, AC4 Post Office, AC5 Creche, AC6 Primary Schools |
| Health | Built environment supports a healthy and productive environment | HE1 Exercise, HE2 Health facility, HE3 Fruit and Vegetables, HE4 Bean and Pulses, HE5 Milk and Eggs, HE6 Water, HE7 External Views, HE8 Daylight, HE9 Openings, HE10 Roof Construction, HE11 Wall Construction, HE12 Volatile Organic Compounds, HE13 Formaldehyde, HE15 Construction Worker Health |
| Education | Built environment supports education. | ED1 Primary Schools, ED2 Secondary Schools, ED3 Ongoing education, ED4 Internet, ED5 Noticeboards, ED6 Space for Learning, ED7 Building User Manual, ED8 Construction Worker Education |
| Inclusion | Built environment is inclusive of diversity in the population. | IN1 Public Transport, IN2 Groceries, IN3 External Routes, IN4 Entrances and Exits, IN5 Lobby, IN6 Window, door, and lighting controls, IN7 Doors, IN8 Bathroom, IN9 Kitchen, IN10 Inclusive Employment, IN11 Affordability |
| Social Cohesion | Built environment supports social cohesion. | SC1 Occupants, SC2 Community space, SC3 External Facilities, SC4 Residents Association |

Assessments are carried out using the criteria in Table 2 and the results generate a report with a rating and graph as shown in Figure 1. The report shown is for the SBAT Residential which measures performance of housing. Ratings for environmental, economic, and social sustainability performance as well as an overall rating is shown. The spider diagram provides an indication, on a scale from 0 to 5, of the performance in different areas.

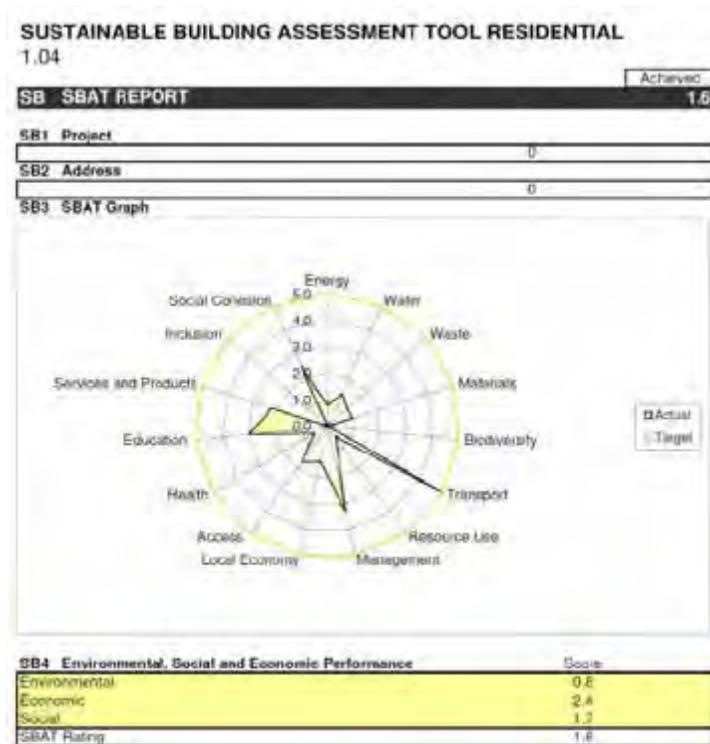


Figure 1. Sustainable Building Assessment Tool Report [14].

DESCRIPTION OF THE CASE STUDY SITE

The case study site is an a 1,000m² developed urban site in Pretoria South Africa indicated in the red rectangle in Figure 2. The site is in a well-established residential neighborhood near the CBD. The neighborhood is wholly residential, and residents generally travel by car out of the neighborhood to access education, retail, recreational and work.



Figure 2. Case study site

The site has an existing freestanding house of about 200m², outbuildings and a pool. This is shown in Figure 3. A section through the house is also shown indicated that the site slopes down to the North

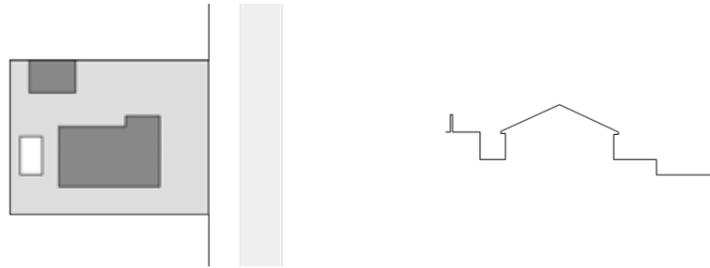


Figure 2. Plan and section through development on case study site

GENERATING DESIGN BRIEFS

To generate structured design briefs, the development is broken into 5 design elements. These are neighborhood services, layout, and form, building services, building envelope and internal layout. A matrix of these elements (on the horizontal axis) and criteria from the Sustainable Building Assessment Tool (on the vertical axis) is then developed as shown in Figure 4.

This matrix enables the implications of SBAT criteria to be analyzed per design element of the proposed development (implications are indicated in the yellow blocks in the matrix). Once identified, implications can be understood, prioritized, and formulated into design briefs for the respective elements. These briefs are organized in a hierarchical manner, requiring designs to be developed first at a planning level (neighborhood services) before moving through to site layout and building form, building envelope to internal layouts.

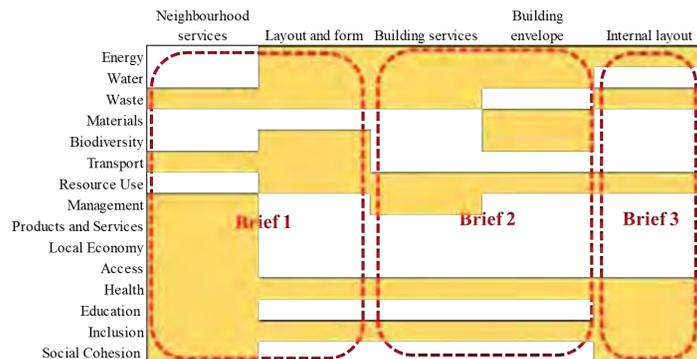


Figure 4. Building element sustainable design brief matrix (developed by author)

DESIGN BRIEFS

Analysis using the matrix in Figure 4 is used to generate design briefs. These include a brief for neighborhood services and layout and building form (Brief 1), building services, and building envelope (Brief 2) and internal layout (Brief 3). In line with recommendations these briefs are design orientated kept very simple [10]. These briefs are outlined below.

Brief 1

Analysis of the matrix provides two key objectives for the design of the development in relation to neighborhood services and building layout and form. These objectives are:

- Provide neighborhood services if these are not available locally.
- Optimize the site layout and building form to achieve required densities, efficient resource use, passive design, and sustainable systems

Fulfilling this brief requires several surveys and studies. First, a survey of the neighborhood is required to establish whether the required neighborhood services are available. Where these are not available, the inclusion of these services in the development needs to be considered. Second, form and layout studies are required to understand how required densities and sustainable energy, water and waste systems can be achieved. Rapid surveys and studies of this nature can be used to generate designs which can be iteratively developed.

This process results in development proposals shown in Figure 5. This shows a three-story North facing block across the site for residential apartments. Facing the street are a range of small commercial and social units that can accommodate neighborhood services. To the North of the residential block there is a garden that is used for food production and leisure. To the South of residential block, there is space to access the apartments and accommodate sustainable services. A key to these spaces and facilities corresponding to Figure 5 is provided below.

1. Service area for renewable energy, water, and waste systems
2. Different apartment types
3. Urban agriculture and recreational use
4. Social services including health and education
5. Commercial services including food and goods retail, mobility, repairs, and rental.

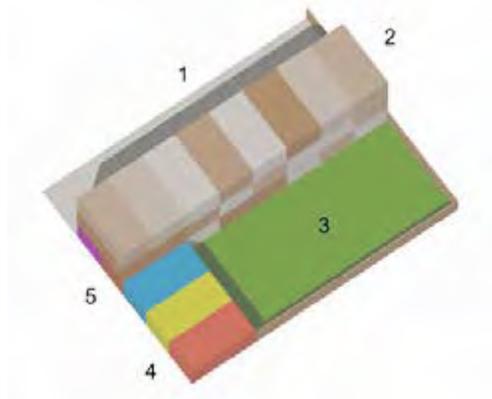


Figure 5. Conceptual building form and layout

Brief 2

Analysis of the matrix provides one key objective for the design of the development in relation to the building envelope. This objective is:

- Optimize the building envelope for IEQ, passive environmental control and sustainable energy, water and waste systems.

This brief can be used to develop and test different design options to develop optimum approaches. This results in the section for the Residential block shown in Figure 6. This shows that the roof is used for solar water panels and photovoltaic panels. The width of the block and the building envelope are developed to support excellent cross ventilation and natural daylighting as well as direct solar gain for heating in winter. A service tower to the South of the block accommodates solar water tanks, batteries and provides access to water, hot water and energy metering systems and controls. Underground tanks are provided for rainwater and greywater systems. A key to the section shown in Figure 6 is provide below.

1. Rainwater catchment
2. Solar water heater
3. PV panels
4. Hot water storage
5. Hot water, electricity, grey water, rainwater and potable water supply meters
6. Apartment
7. PV inverter, battery, and controls
8. Incoming potable water mains
9. Rain and grey water storage

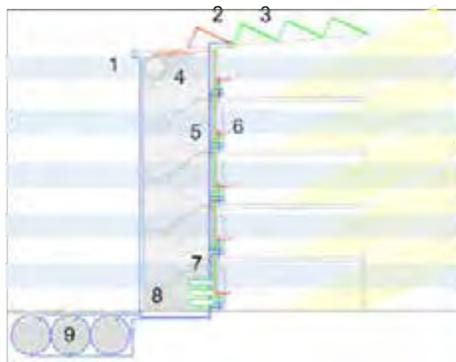


Figure 6. Conceptual building section of the proposed development

Brief 3

Analysis of the matrix provides one key objective for the design of the development in relation to internal layouts. This objective is to:

- Accommodate residential, social, and commercial functions efficiently and flexibly while achieving high indoor environment quality.

This brief requires studies on the requirements of the proposed functions and how these can be accommodated in the proposed development. This process leads to a modular approach in which different functions can be accommodated, as shown in Figure 7. This simple module supports 1 bed, 2 bed and 3 bed apartments. It also accommodates social and community units such as a small creche and gym as well as commercial units such as vegetable and fruit retail. A key to this accommodation indicated in Figure 7 is outlined below.

1. Residential units including 1B, 2B, 3B units.
2. Social and community units including creche, gym, community area
3. Commercial units including vegetable and fruit retail, grocery, ICT support and business services, bike hire and repair, tool hire and repair, furniture, and clothing

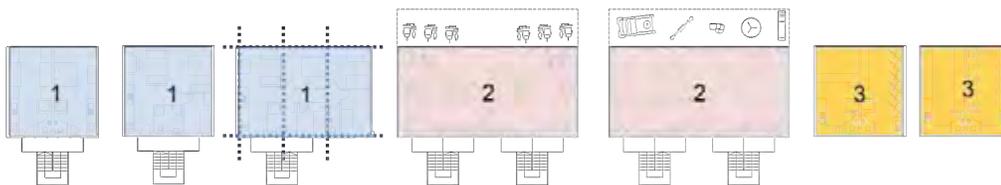


Figure 7. Modular plans of proposed development

SBAT ASSESSMENTS

To understand the value of the approach assessments of the existing development and the proposed conceptual development are carried out and shown in Figure 8. Figure 8 shows the site layout, a section, and SBAT reports for both the existing development and the proposed conceptual development.

The SBAT assessment of the existing development indicates this achieves a rating of 1.7 which reflects poor sustainability performance. The assessment indicates the development performs poorly against most criteria other than Biocapacity, Transport and Access.

The SBAT rating of the conceptual proposal is 4.2 which indicates strong sustainability performance. The assessments indicate high performance in terms of nearly all of the SBAT criteria strong holistic performance.

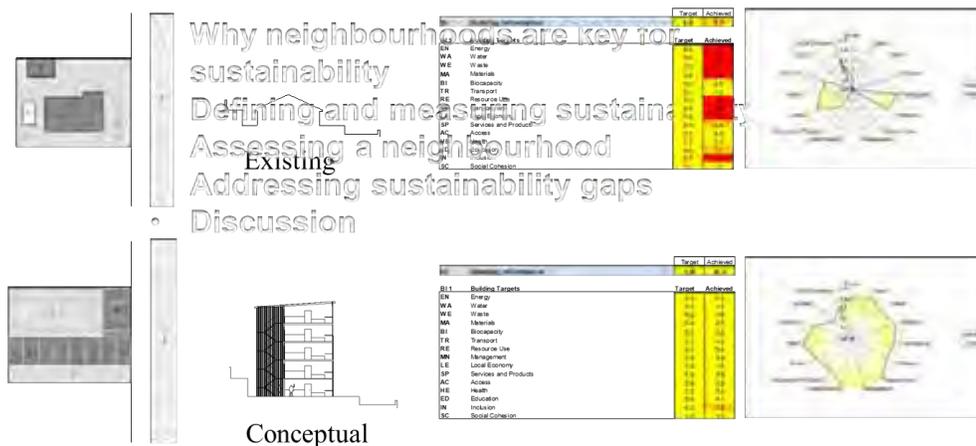


Figure 8. SBAT assessments of existing and conceptual designs

DISCUSSION

The study is exploratory, so conclusive results are not expected [13]. However, insight from the findings can be discussed using the following questions. First, does the approach appear support a focus on key sustainability issues and their integration in new developments? Second, does the approach support the development of high-performance sustainability designs?

In terms of the first question, it appears that the process helps to support a focused design approach that addresses the key sustainability issues. A complex and comprehensive rating tool with 15 sets of criteria (the Sustainable Building Assessment Tool) is translated into a set of hierarchical simple design briefs for the main elements of a development. These simple design briefs enable key design decisions to be made in a hierarchical manner and appear to help generate integrated and cohesive proposals that are responsive to the local context. The simplification of objectives appears to help enable key sustainability factors to directly generate and shape the main elements of the development [10]. The requirement to carry out local studies, for instance of neighborhood services and building form and shape studies, appear to help ensure that the local issues are considered and addressed in designs [11].

In terms of the second question, it appears that the methodology leads to a design that performs well. It also appears to support strong holistic performance in that performance across all the SBAT criteria is good and this not uneven. For instance, performance can be compared favorably with the very uneven performance of the existing development (Figure 8). This suggests that the use of simple design briefs may help to generate designs that achieve high performance sustainability performance. The methodology therefore appears to help ensure that sustainability is effectively integrated into design decisions related to key building elements such as a) the type of functions accommodated on site, b) the layout and form of buildings c), the building envelope d), internal layouts and e) integrated off-grid service strategy. Thus, the approach consisting of analysis of sustainable building assessment tool criteria and hierarchical design briefs appears to support the generation of development proposals and designs which achieve both holistic and strong sustainability performance.

CONCLUSIONS AND RECOMMENDATIONS

The study develops and critically reviews a methodology that translates sustainable building assessment tool criteria into hierarchical design briefs for building elements such as neighborhood services, building form, building envelope, building services and internal layouts. The methodology is tested by applying this to an urban case study site in Pretoria, South Africa to develop a conceptual development for the site. An assessment of the conceptual development is found to score well in terms of sustainability performance. The findings suggest that the methodology can be used to help integrate sustainability into design processes and help support the development of buildings and sites that are more sustainable. It is recommended that the methodology is developed further.

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BIO-GEO-PHYSICAL CONDITIONS

The city commits to responsible management of resources and materials as well as the generation and use of clean, renewable energy. It maintains a level of physical conditions that ensure clean air and access to clean and safe water. It fosters healthy soil and makes sure nutritious, locally grown food is available.



ENVISIONING SPONTANEOUS FOODSCAPES FOR FUTURE DHAKA: REVITALIZATION OF A NATIVE PRACTISE TO BOOST THE URBAN GREEN INFRASTRUCTURE

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ABSTRACT

Traditionally, Bangladesh is home to a vast agrarian community. The vernacular agricultural systems of native Bangladesh have shaped the characteristic features of her cultural landscapes depicting plentiful measures of producing food. Quite contrary to the green refuge offered by the countryside, the drastic urban settlements of Bangladesh convey a sense of acute congestion and pollution. An obvious example for this could be the megacity of Dhaka. The city's decaying and dispersed green patches are proof enough that the city never had a planned green infrastructure. Therefore, very few city dwellers have adequate access to green and healthy public realms, not to mention the increasing loss of ecology and biodiversity. To ensure a healthier and eco-friendly living environment for the city dwellers, the city needs to fill the gap in its green infrastructure. One of the socio-economically and spatially viable ways of achieving that could be the retrieval of the native practise of food production. In recent times, community gardening and foodscapes have become a popular urban culture in many cities worldwide. Mapping some sample streets of Dhaka, some such spontaneous practises are noticed. In the scope of this research, appropriate urban foodscape ideas would be proposed in a case study area to envision Dhaka's future green infrastructure. Keeping the city's dire spatial inadequacy in mind, the point to be explored here, is how the essence of this impulsive native practice of the Bangladeshi people can help attain a healthier living environment ensuring a balance between ecology, economy, and social participation.

KEYWORDS

Green infrastructure; urban foodscape; agriculture; productive landscape; urban farming

INTRODUCTION

Bangladesh and its inherent foodscapes

The earliest inhabitants who migrated to the fertile terrains of riverine Bengal, had the culture of cultivating crops and rearing animals even before 1500 BCE. The livelihood of most of the locals here have traditionally depended on agriculture. In the Bengal delta landscape, from an early time, the high lands were dedicated for homesteads and orchards, the lower grounds were used for rice seedlings and vegetables, and the lowest lands and floodplains for rice cultivation [1]. These vernacular agricultural systems have led to the characteristic features of the cultural landscapes of Bangladesh and the spatial attributes of its living environments. It may be even said that the romantic cultural landscape as well as the natural beauty and diversity of traditional Bangladeshi villages, to a large extent, come from the numerous ways the locals produce their food (Fig. 1).



Figure 1. A collage of three images of cultural landscapes in rural areas of Bangladesh

The homestead vegetation, forestry and cropland areas embedded in the native Bangladeshi lifestyle, are not only one of the major sources of rural agrarian economy, but they also have a wide array of ecological services. These green areas provide shade, building materials, shelter, recreation, peace of mind and at the same time, preserve the native eco-systems. Many a time, these food-producing vegetal covers protect the rural households from natural and climatic adversities such as intense heat or winds [2]. Where the natural forest cover in our country is less than 10%, homestead gardens that are traditionally maintained by almost 20 million households may reinforce the conservation of soil, water, nutrients, and biodiversity [3].

The decline of urban green in the context of Dhaka

Although the rural realm remains a green oasis, the ever-growing urban areas of Bangladesh portray a stark contrast to that. Filled with unplanned development activities and increasing population pressure, the city areas are filled with acute congestion and pollution. The megacity of Dhaka can be an appropriate example in this case. Back in the 17th century at the time of its establishment, Dhaka was a lush green city filled with numerous waterways and green areas. The city's plentiful green landscapes are now a thing of the past. The rural-urban migration has drastically doubled the city size from 1990 to 2005 [4]. The high population density and drastic infrastructural developments of Dhaka are major driving factors for the destruction of green spaces and land-use and land cover changes over the years [5]. Even though it is required for a city to have at least 20% of green space, Dhaka only has 8.5% [6]. This gradual loss of green spaces leads to a decline in biodiversity [7]. From the timeline mapping of Dhaka city in Fig. 2 done on the basis of a study by Ahmed et al. [8], it can be seen how the green and blue areas of Dhaka city are gradually diminishing over the years.

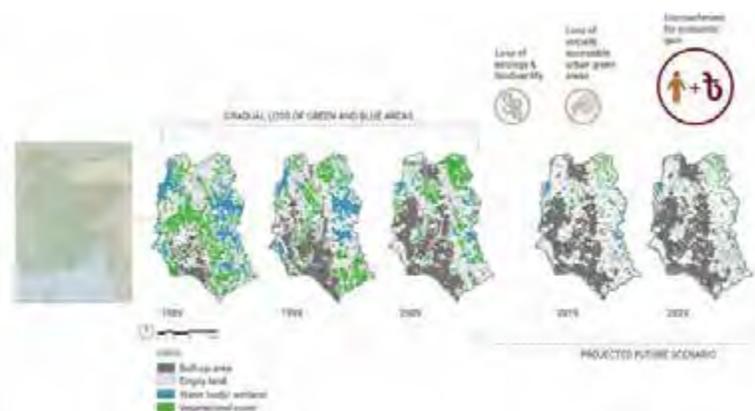


Figure 2. Dhaka's gradually decaying green and blue areas

The above mapping clearly indicates that Dhaka never considered a green infrastructural planning as part of its development process. By green infrastructure, here we refer to a strategically planned and delivered network consisting of high-quality green spaces and other environmental features which is designed and maintained as a multifunctional and sustainable resource to deliver ecological services and quality of life benefits for the community. The green infrastructural linkages need to be delivered at all spatial scales from sub-regional to local neighbourhood levels and should accommodate accessible natural green spaces within local communities [9]. Two vital components of green infrastructure are hubs and links where hubs refer to areas of natural vegetation, other open space, or areas of known ecological value, and links are the corridors that connect the hubs to each other [10]. An urban green infrastructure can improve human health and wellbeing, reduce urban temperature, act as carbon sink, improve air, water, and soil quality, induce biodiversity, and boost up the urban economy [9]. One of the most prominent and ever-expanding infrastructural links (though sometimes unplanned) that we can see on Dhaka's map (Fig. 3) is undoubtedly the city's grey network of road systems. Dhaka, as a city, fails to address the fact that the green infrastructural linkages and socio-ecological hubs/hotspots are equally important, even not more, as the other hard infrastructural development ventures.

Dhaka, over the years, has achieved such a level of density and congestion, that it is hard to envision a new plan for the city's green infrastructural hubs and links. From the mapping of Fig. 3 two inner city (google earth) aerial views can be seen that show the density of formal and informal settlements. There is hardly any space for new ecological corridors or links. Another problem for Dhaka is its unplanned and insensitive peripheral sprawl. After the liberation of Bangladesh in 1971, Dhaka became the capital city of Bangladesh and started expanding in all directions keeping bare minimum porosity in the urban tissue [4]. Dhaka's peripheral areas are giving way to unplanned growth of industries and residential sites that are gradually eating up the cultivable lands, flood plains and the existing natural/ cultural landscapes which could be potential ecological and socio-cultural green hubs. In the mapping of Fig 3, (google earth) aerial views from four points located at the north, south, east, and west periphery of Dhaka have been depicted and in every case, there is either illegal factory encroachment by the peripheral waterways or unplanned development over peripheral wetlands.

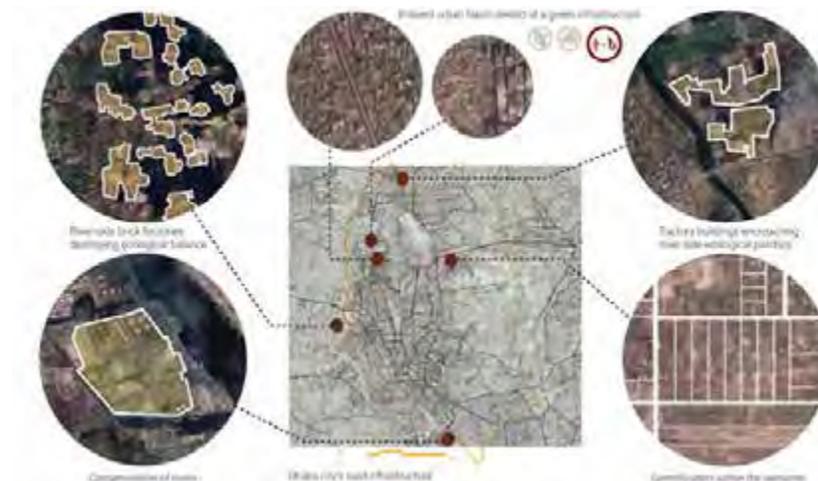


Figure 3: Dhaka's ever expanding road infrastructure, inner-city congestion, and peripheral land consumption

There is a sheer lack of awareness among the urban populace as well as the policymakers about the ecological services, social, environmental, and economic benefits of green infrastructure in a city like Dhaka. They are reluctant to conserve the green areas and more attracted towards hard infrastructural developments as they seem to think that these would bring short-term economic returns whereas green areas or ecological hotspots are not income generating. As a result, the city dwellers are suffering from a severe scarcity of accessible green open public spaces (which can be seen in the inner-city mapping of Fig. 3, decline of ecology and biodiversity and a lack of connection and belongingness to the city. Fig. 4 depicts how empty lots and roadsides are indiscriminately used as dumping grounds by the city dwellers themselves.



Figure 4. A collage of three images depicting empty lots and roadsides being used as dumping grounds

Possibility of spontaneous foodscapes as part of Dhaka's future green infrastructure

Despite all the above-mentioned acute adversities and challenges, Dhaka city needs to provide a healthier environment for its dwellers ensuring public access to green open spaces and add socio-economic incentives to these green spaces so that they are spontaneously maintained by the community. One of the major challenges in attaining that is the dire inadequacy of space in this congested urbanity. While imagining a greener future for such an overburdened city, a viable option might be to seek refuge in our native food producing landscapes. These new urban foodscapes could be income generating and hence spontaneously maintained by the urban population while reinforcing the urban ecology and green infrastructure. They can be source of new urban activities and social interactions as well and thus increase the belongingness of the urban population to their own city. Therefore, the aim of this research was to find out if spontaneous foodscapes can be a viable option to reinforce the green infrastructure of Dhaka. The research also tried to find out where we can accommodate such practises in a congested city like Dhaka and how these foodscapes can be managed and get integrated with local urban communities.

METHODOLOGY

To assess the viability of spontaneous urban foodscapes for strengthening Dhaka's green infrastructure, a case study area (located in Mirpur) was selected within Dhaka. The Mirpur area was initially mapped for identifying numerous micro-scale spontaneous food production practices by the locals. Based on the initial mapping and precedent studies (native and foreign), a set of micro-scale design principles were derived. As a multi-scalar landscape design approach, the principles were then applied in the micro and meso scales of Mirpur area and macro scale of Dhaka city to envision the new links in Dhaka's future green infrastructure.

Mapping spontaneous foodscapes in the case study area of Mirpur, Dhaka

Mirpur is an area located within the North City Corporation of Dhaka and falls within the comparatively newer development phases of Dhaka. As can be seen in the map, the Mirpur area holds a moderate to high density in its urban fabric interspersed with dense road infrastructure and the western edge of Mirpur is in Dhaka's west periphery. Therefore, both the inner city and peripheral conditions could be mapped within this area.

The spontaneous food producing practises were mapped by traversing the main roads, secondary roads, and intimate neighbourhood streets of Mirpur area. Quite a few urban farming ventures were spotted during the mapping. Fig. 5 shows the different types of micro urban foodscapes that were identified.



Figure 5: Mapping of spontaneous food producing practises in Mirpur, Dhaka

While roof gardens are most common all over the area, some pop-up farming activities were also noticed on the setback spaces or apartment buildings, on the side of wide footpaths, on the tin-shades of informal settlements, and on some of the islands of major roads. These small patches were mostly occupied by gourds and other vegetables, amaranths, taro, and plantain trees. At the peripheral

zone of Mirpur, newly proposed housing plots were found to be allotted to local farmers by the owners for harvesting different types of vegetables all the year round. During the months of lockdown due to COVID in 2021, some school playgrounds of Mirpur area were seen to be used for vegetable cultivation. A small cow farm was also spotted selling fresh milk at the side of a major road in Mirpur.

The presence of above instances of spontaneous urban foodscapes depicts the fact that many city dwellers of Dhaka belonging to both formal and informal settlements are quite fond of engaging with the traditional culture of producing foods for recreational or economic purposes. The different types and locations of these practises also show the numerous possibilities of placing spontaneous foodscapes within the dense urban fabric of Dhaka.

Study of native precedents of foodscapes

Rural homestead food sources: To realise how deeply food production is embedded in the vernacular lifestyle of Bangladesh, one of the most rudimentary forms of riverine settlements found in the present-day Bangladesh, namely the deltaic river *Chars* (Fig. 6) can be studied. Looking into the macro-scale aerial view of a river island, an intricate mosaic of green and brown shades can be observed that are created by crop-fields and tree-covers along with the habitation. Further zooming into the meso scale, the higher homestead patches are found surrounded by native fruit-bearing plantation and homestead gardens/forests. Zooming further in the micro scale, a single homestead can be seen to produce its own food resources from the pond that was dug to higher the base of the house and from the numerous fruit and vegetable plants in and around the elevated homestead base. The spatial arrangement of the dwelling is such that it harnesses all sorts of food producing endeavours of the house owner.

The principle to be learnt from these food producing ventures is that they are multi-functional achieving a balance between economy, ecology, and societal needs. They are not only providing food but supporting native ecology and biodiversity with a mixture of productive plantation such as plantains, fruit trees, timber producing native trees, coconut and betelnut trees, vegetable beds and trellises which attract a wide array of birds, insects and small terrestrial animals and a pond filled with aquatic flora and fauna. Apart from economic and ecological benefits, these foodscapes are also creating spaces for pleasant social interaction, household activities and natural play spaces for children.



Figure 6: Char habitation and its foodscapes in macro, meso and micro scales

Rural homestead forests: Homestead Forest is generally a patch of plantation in between rural homesteads that are maintained by adjacent house owners. These types of forests can be found in most areas of Bangladesh. A homestead forest is the source of fruits, vegetables, firewood, cattle fodder, building materials and numerous other ecological services. Generally, a homestead forest consists of fruit and timber producing local trees, local figs and berry shrubs, different sorts of native herbs, edible taro plants etc (Fig. 6). These forest patch works as a biodiversity hotspot as the dense canopy and of different trees and shrubs provide food and habitat for birds, small terrestrial animals, and insects.



Figure 7: Native homestead forest of Bangladesh in macro, meso and micro scales

The principle to be learnt from this native foodscape precedent lies in the bigger scales. From the meso and macro scale views in Fig. 7, it can be seen that multiple homestead forest patches together form a larger network of ecological corridors. Similarly, if micro scale spontaneous urban foodscapes can be systematically arranged, they can strengthen the urban green infrastructural links and ecological corridors.

Floating vegetable gardens: Floating vegetable beds are characteristic features especially of the southern wetland areas of Bangladesh (Fig 8). The farmers of these flood prone areas have adopted a floating system of vegetation as their cultivable lands stay under water every year for a substantial period during the rainy season.



Figure 8: Floating vegetable gardens of Bangladesh in macro, meso and micro scales

These elongated beds are made from water hyacinths, water lettuce, duck weed etc. that are found in abundance in the stagnant waters of Bangladesh. The construction technique of the beds is eco-friendly and affordable. Also, during the dry seasons, the organic materials from the bed can be used as fertilizer for dry agricultural lands. These beds are easily portable and maintained by farmers using boats. Farmers cultivate various gourd vegetables, taro plants, spices and leafy vegetables and numerous other vegetables on these beds requiring no additional fertilizer. As water hyacinths and duckweeds are invasive plants and reduce oxygen level of the waterbodies, these floating vegetable beds help to control their infestation and improve the aquatic environment. Learning from this low-cost, eco-friendly venture of the native farmers, similar measures can be taken for Dhaka's dying canals and stagnant water bodies that are under threat of encroachment or landfill. These floating beds can be an extra source of income and a new urban attraction for local communities.

Study of foreign precedents of foodscapes

Food independence in Cuba: In addition to the native foodscapes, the rewarding, engaging and resourceful practice of urban farming is an emerging trend worldwide. For example, Cuba is now a world leader in sustainable agriculture and the most renowned of its achievements comes from the thriving urban farming ventures. This socialist nation has been long burdened by trade embargoes by the U.S. and the termination of the Soviet bloc in 1989. Cuba has since then, capitalized this isolation to evolve into its resilient self where urban farming played a major role. Havana's food producing urban green infrastructure is a series of farm typologies that functions like a "kit of parts". These parts while contextually responsive, unique, and independent in their own realms at multiple scales, form a sustainable and productive green environment as a whole. The crops include vegetables and herbs, medical and ornamental plants, flowers, fruits, plantains, coffee, cocoa, roots and tubers, oil seeds, rice, beans, corn, and sorghum. This network also supports livestock such as poultry, rabbits, guinea pigs, sheep, goats, pigs, and cows (Fig. 9). Other than food resilience, this flourishing urban food culture offers an array of other benefits. It fosters a new urban ecology that reinforces natural processes as well as social and civic engagement. Also, the production and consumption both happening within an urban realm, helps attain circularity in urban flows such as food or waste. The bottom-up nature of these sort of spontaneous practices provides greater belongingness to the city for its dwellers [11].

Apart from the innovative urban farm typologies, the point to be learnt here is how the individual urban farming ventures can come together to form a large scale urban green infrastructure while greatly improving the urban socio-economic condition.



Figure 9. Graphical representations of urban farming schemes in Cuba

FareShare Kitchen Garden, Abbotsford, Melbourne, Victoria, Australia: FareShare kitchen garden was initiated back in 2016 on a small plot of approximately 2,800m² (Fig. 10). This wasteland is leased from Vic Track formerly used by Victoria rail to grow vegetables for the "FareShare" – Australia's largest charity kitchen. The whole initiative is run mostly by charity and volunteers under the guidance of a small management team. The wasteland was prepared through putting layers of sandstone, plastic, woodchips, and soil over the non-arable site. An intricate irrigation system has been installed to irrigate 70 vegetation beds of approximately 800m². The garden is producing organic vegetables like eggplant, cauliflower, zucchini, carrots, silver beet, sweet potatoes etc. using a crop rotation system over different seasons. Composting is also an important mechanism here using kitchen and garden waste to keep the health of the soil. Moreover, the garden has flower plant species to attract bees and other species to support pollination and pest control. The garden offers fresh and quality vegetables for the FareShare Kitchen preparing nutritious food to feed vulnerable people struggling to access nutritious food. This whole edible gardening initiative also works as a training platform for the beginners in terms of organic urban agriculture, composting etc. [12].

This precedent shows how an unused non-arable site can be transformed into an urban agricultural platform which addresses the issue of food security of the vulnerable communities, effective organic food production, biodiversity, education regarding food production and community bonding through charity. This kind of vegetable gardens have also the potentials to become vital open spaces of the green-blue infrastructural network of any given urban context generating various social and human activity.

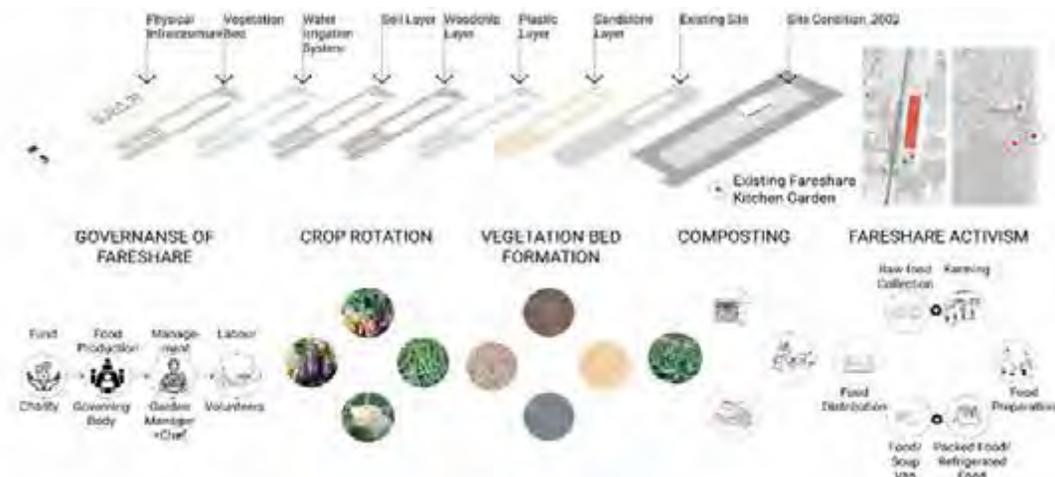


Figure 10: Analysis of different components and services of FareShare Kitchen Garden

Design principles for spontaneous foodscapes of Dhaka

Based on the mapping in the case study area of Mirpur and precedent studies both local and foreign, a set of design principles were derived that can be implemented as spontaneous endeavours by an individual person as well as a group or institution (Fig. 11). If a large portion of the urban population adopted these individual micro scale design principles, the city could have an organically grown green infrastructure as a whole. This could be a flourishing urban green infrastructural network that is edible, feasible, functional and at the same time aesthetically pleasing, culturally involving, and socially engaging. While having the most prominent and visible impacts in the micro and meso scales, this could even lead to a macro scale shift of urban climate, ecology, and overall environment. All the selected design principles meet three basic design criteria of economic returns, ecological balance, and active engagement of the society. The principles are as follows:

- Multi-level foodscapes: fruit-bearing plants, vegetables, birds etc. can make up a micro farm on the various empty spaces and layers of urban multi-storeyed buildings including their setback spaces, balconies, and rooftops.
- Informal foodscapes: informal settlements, squatters and slums are a brutal truth of urbanity in Bangladesh. They are mainly occupied by migrating population from rural areas who come to the city in search of a livelihood but never can feel to be entirely belonging to the metropolis. Growing their own food or even a portion of the daily meals in the rooftops or periphery of their temporary living quarters can give them a sense of belongingness to their living environment and provide them with economical or nutritional benefits.
- Food-backs: the combined setback spaces and narrow allies that are mostly considered as negative spaces amid the built environment of neighbourhoods, can be harvested for easy growing vegetables and fruits like taro, gourds, or berries.



Figure 11: Design principles for spontaneous urban foodscapes in Dhaka

- Floating foodscapes: the native knowledge of floating vegetable beds on water hyacinth plants can occupy some of the water courses in and around the city. The edge of the water canals can be used for hanging vegetable fences and riparian buffers. The urban ponds can be used for fish cultivation. These could bring economic and ecological benefits as well as creating aesthetically pleasing waterscapes. At least, by starting to practice these ideas, the policy makers and the general populace could be encouraged to raise more awareness and stop encroachment of existing water systems.
- Food-paths: continuous bands of herbs, vegetable, or fruit plant patches could be placed on the side or over-head areas of urban footpaths. The yields could be harvested by local governing authorities or volunteers from public.
- Food-islands: the islands in the middle of major roads can be occupied by edible landscapes that are both aesthetically enjoyable and a source of food and economy for people.
- Food-institutions: the vacant spaces adjacent to the play areas of community school grounds and government offices can be occupied with foodscapes. In case of school grounds, the children can engage with nature, ecology and gain the knowledge of food production and at the same time, spend time in healthy outdoor activities with their elders.
- Food-periphery: the peripheral lands of the growing city can be dedicated for foodscapes as a source of urban recreation, urban agrarian economy and a strategy to contain urban growth by creating an outside green edge in the urban green infrastructure.

Application of the design principles to envision Dhaka's reinforced green infrastructure

After deriving the design principles, the reinforced green infrastructure of Dhaka city is envisioned in three different scales such as the micro scale of the built environment, the meso scale of the case study area of Mirpur and the macro scale of the entire city (Fig. 12). In order to apply the design principles, two micro scale test sites were selected within Mirpur area. One of the sites consisted of a mixed-use building along a secondary road where the principles of multi-level foodscapes, food path, food island and food backs were applied. The other site was chosen at the west periphery of Mirpur on the bank of a canal parallel to the Turag River in an informal settlement context. Here the principles of informal foodscapes and floating foodscapes were applied. In the meso scale of Mirpur area, it can be observed that green layers appear along the road infrastructure by placing spontaneous foodscapes along the roads on adjacent building peripheries, foot paths and road islands. On the west periphery a large green area is created by implementing foodscapes in the peripheral lots. In the macro scale of Dhaka city, a new urban green infrastructure is envisioned where the large green patches are connected by green infrastructural links created by different spontaneous urban foodscape ventures.



Figure 12. Envisioning Dhaka's reinforced green infrastructure with spontaneous foodscapes in micro, meso and macro scales

DISCUSSION

While the existing pop-up foodscapes of present Dhaka are providing economic benefits and leisure opportunity for their owners to some extent, these ventures are mostly dispersed, isolated and do not cater a collective approach. As they are scattered as individual points, they are not able to form ecological corridors in the urban fabric. Mostly these are individual ventures without any systematic arrangement or specific infrastructural support.

The proposed principles derived from this research aim at a multi-scalar approach to ensure balance between ecology, economy, and societal needs. They provide options for individual, community or institutional ventures and create scope for multiple use of public infrastructure such as foot paths, road-islands, institutional open spaces, and public peripheral land parcels. These principles are meant to be applied as a continuous network rather than individual points so that they can build up ecological corridors at larger scales and create greener environments for the city dwellers as a whole. As it has been mentioned earlier that Dhaka has a dense tangle of road infrastructure, harnessing that infrastructural link may provide the city with a strengthened green network as well. The spontaneous foodscapes in the public grounds and waterways have the possibility to generate new activities, recreational facilities, and economic returns for people. These incentives will encourage general population and the policymakers to conserve urban open spaces and stop illegal encroachment or unplanned development activities. At the macro scale, the spontaneous foodscapes together can contribute to urban food supply as well.

In order to achieve the greater scale impact of spontaneous foodscapes in Dhaka, creating necessary awareness about the present environmental and socio-economic adversities and at the same time about the positive impacts of spontaneous foodscapes is a prerequisite. From the many scattered practices of urban farming of present Dhaka, it can be undoubtedly said that the city dwellers are enthusiastic to revive their native practice of food production in their urban life. But to strengthen the city's overall green infrastructure, greater public awareness and incentives are necessary which can be initiated by related government authorities and NGOs.

CONCLUSION

Dhaka has become an utterly congested and grey metropolitan with its ever-increasing migratory population pressure and random development activities. The green areas of Dhaka are decreasing every day inducing loss of ecology and overall living quality of the city. But this harsh reality may be ameliorated by reminiscing the native Bangladeshi custom of agriculture and food production. Growing their own food have never been alien to the locals starting from the very first human settlements in this country. The picturesque rural areas are filled with spontaneous and nature-friendly food producing enterprises. If some of these impulsive food growing practices can be brought into the urban realms, new possibilities can be created to restore or newly build linkages in the existing urban green networks and attain a desired balance between ecological, economical, and societal needs of the urban community.

In its limited scope, the research has tried to depict the existing situation and potentiality of spontaneous foodscapes as alternative green infrastructural links for future Dhaka. Due to the limited timeframe and resources, the survey included only qualitative mapping of the existing food producing ventures. In a greater scope, maybe a quantitative analysis regarding the percentage of population involved in spontaneous foodscapes could also be sought. Also, the derived principles, by no means, cover the entire repertoire of spontaneous foodscape options but are only a compilation of some ideas that might lead to many others in future. Also, further research and design ventures can be taken for pilot implementation of the design principles in both private and public realms that might lead to their enhancement and raise public awareness.

In conclusion, it may be said that the spontaneous foodscape design principles and their larger scale impact is subject to future discussion, further investigation, experimentation, and pilot implementation. This research has just tried to depict a future vision and new hope for a city that is losing its livability day by day. Necessary awareness and spontaneous participation from both the Government and public can initiate a greener city at a larger scale in the coming future.

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QUANTIFYING AIR TEMPERATURE IN THE GREY AND GREEN SPACES OF AN URBAN HEAT ISLAND

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ABSTRACT

Whilst it is broadly understood that urban green infrastructure (UGI) helps to mitigate against the urban heat island (UHI) effect, there remains a relatively small body of measured data that quantify the impact of UGI on urban temperatures. This paper presents interim results from a long-term monitoring campaign in the city of Leeds, UK. A network of air temperature sensors housed in Stevenson shields were deployed across Leeds in the summer of 2019. Initially, a total of 17 sensors were included in this network: 10 in grey (man-made built-up areas) urban spaces, 5 in UGI, and 2 sensors at rural reference sites. The data set reported in this paper covers the period July 2019 to November 2020 at an hourly resolution. Results characterise the urban heat island intensity (UHII) and the differences between air temperatures in the urban grey and green spaces. There are both diurnal and distinct seasonal differences in the hourly temperature data. The average UHII during this period was 1.8 °C, with a summer peak of 4.9 °C occurring in late evening. Within the UHI during summer months, the green space was on average 0.5 °C cooler than the grey spaces and up to 2.8 °C cooler on the hottest days. These measured data quantify the local cooling effects of the green space, which is useful at both a macro city-scale and micro citizen-scale. Results of this nature are useful in building a quantitative evidence base that supports the retention and introduction of urban green infrastructure.

KEYWORDS

Urban heat island; Urban green infrastructure; Leeds, UK

INTRODUCTION

Changes in land use related to human activities have led to many cities becoming hotter than their surrounding rural areas, a phenomenon described as the Urban Heat Island (UHI) [1-4]. Whilst the UHI effect has been acknowledged since at least the 1950s [4], research in this field has grown exponentially in recent decades as sensor technologies have matured and been more widely deployed [5, 6]. Availability of remote sensing data, more affordable ground based sensors, and the individual nature of the UHI from city to city have all played a part in this growth of research activity [7]. Subtropical, Mediterranean and Arid climates can experience the most extreme instances of UHI intensity (UHII) [3, 5, 6] but Maritime climates, like that found in the UK, are also subject to this effect, with summer overheating becoming more common [8-12]. The first part of this paper quantifies the UHII in the city of Leeds during the period July 2019 to November 2020 using measured ground-level air temperature data from 18 city centre sensors and two rural reference sites; the Leeds UHI during the summer heatwave of 2013 has been quantified in previous work [13]. Results illustrate the diurnal patterns of the UHII during this period and also the significance of the rural reference site used in the calculations.

As understanding of the UHI has increased, the potential to mitigate the effect has been explored across the globe [3, 14, 15]. Mitigation measures that can help to reduce the UHI include the orientation of buildings relative to sun and wind exposure, reflective coatings for buildings and landcover (pavements and roads), bodies of water and green infrastructure [14]. Urban green infrastructure (UGI) is amongst the most commonly studied mitigation methods, with shade from trees, ground vegetation (including parks), green roofs and green facades all having been cited as helping to reduce urban temperatures [3, 14-18]. The second part of this paper uses measured data from the urban sensors to quantify the difference between the grey and green space. Diurnal and seasonal patterns of the temperature differences are presented in this work. The overall aim of the research is to describe quantitative high-resolution data that demonstrates the impact of green infrastructure in UHI areas, which will in turn help support the retention and addition of urban green space.

LITERATURE REVIEW

When urban areas are frequently subject to higher temperatures than surrounding suburban and rural areas, this is described as an Urban Heat Island (UHI) [4, 8]. The UHI effect is manifest in both urban air temperature and surface temperature [5]. Satellite data can be used to quantify UHI effects on surface temperature over large urban areas but inferring local air temperature from these data is a non-trivial exercise [19-21]. As satellites are only able to provide data for a distinct and short period of time, ground-level measurements are the most effective means of characterising UHI effects at an hourly and diurnal resolution [19]. This is important as the more extreme effects of the UHI have been shown to be greatest during nocturnal hours; daytime air and surface temperatures can often be similar in UHI areas, whereas air temperature during the night can be significantly higher [8, 22-25]. Higher air temperature during the night exacerbates overheating and reduces the efficiency of active cooling [21, 26-28]. More serious health conditions including heat stress, heat rash and cramps, heat exhaustion, heat stroke, exacerbation of cardiovascular disease, and in the most extreme cases, premature death, have all been linked to the higher temperatures found in UHIs [29-34].

Globally, larger cities are estimated to have an average UHI intensity of between 1 °C and 3 °C, but these values differ between individual cities due the range of factors that can influence the UHI [35]. Meteorological factors such as wind speed and direction and cloud cover have an impact on the UHI [24, 36] as do physical changes to landcover, with manmade materials having a low albedo and increased thermal mass that mean less heat is reflected and more heat is stored in the city as a whole [24, 37]. A mean UHI intensity of approximately 2.5 °C has been recorded for European cities but peak intensities during nocturnal hours can be much higher, up to 8 °C in Barcelona and 16 °C in Athens [38]. This is reflected in results from studies in China and the USA, with nocturnal peaks of 8 °C and 5 °C recorded in Beijing and New York respectively [20, 39]. In the New York study, daytime UHI was often much lower during daytime hours and this is also true of studies carried out in the UK, where the UHI is predominantly a nocturnal issue [8, 12, 25, 40]. A mean daily UHI of 2 °C has been calculated for London but night-time peaks in UK cities are also significantly higher, with peak summertime values of 8 °C being recorded in London and Manchester, and a peak value of over 7 °C in Birmingham [8, 41-43].

Along with other measures such as reflective coatings, green infrastructure, including parks, trees, green roofs, and green facades can all help to reduce UHII [3, 14]. Studies including both measurement and modelling have been carried out in an attempt to quantify the impact that green infrastructure can have. As the measurement of green space impact can be resource

intensive, physical modelling approaches provide a useful means to understand the mitigation potential of green space. Physical law-driven modelling can be used to theoretically quantify the impact of green infrastructure, green roofs have been predicted to reduce discrete local air temperature by between 0.4 °C and 1.7 °C, and green façades by 1.6 in tropical climates; peak reductions have been modelled to reach as high as 4 °C for green roofs alone [44-48]. Model results compare closely with measured data, green roofs reducing monitored temperatures between 0.3 °C and 2.4 °C, in tropical climates [49, 50]; a UK study measured an average local reduction of 1.1 °C [51].

Modelling can also simulate the impact of larger UGIs, including trees, small parks and larger parks containing a mixture of UGIs. Small groups of trees have been predicted to reduce air temperature by between 0.8 °C and 1.5 °C, and parks have been estimated to reduce temperatures by between 1 °C and 1.8 °C [44, 47]. Using a data-driven model that combines remote sensing and ground level inputs found that UGI cools European cities by an average of 1.07 °C, and up to 2.9 °C in some cases [52]. Whilst UGIs are most commonly associated with cooling effects, the complex biological processes of plants can in some instances lead to warming during different times of day and in different seasons [53]. Using examples from across the globe, Meili et al report daytime cooling effects from trees of between 0.5 °C and 3.5 °C; this effect is reduced during nocturnal hours, with cooling between 0.3 °C and 0.5 °C, but also examples of warming overnight of up to 0.6 °C [53]. There are also reported cases of warming effects from trees during springtime and summertime daylight hours of between 0.2 °C and a maximum of 0.7 °C, in part due to the evapotranspiration process and latent heat transfer [53].

There is more published measured data for the mitigating effects of parks in particular. Measured data have shown mean reductions in urban air temperatures in small parks in high-density cities of between 1.1 °C and 2.9 °C, with some differences between mean air temperature as high as 4.5 °C (Ghardaïa, Algeria) and 6 °C (Sacramento, USA) [54]. In studies specific to the UK, a large urban park in London was shown to be on average 2.5 °C cooler than surrounding areas, and up to 4 °C cooler at peak times [17]. This compares with a relatively low measured mean reduction of 0.4 °C in Glasgow in Scotland [55]. The cooling effect of urban green space is highly dependent upon the size and shape of the spaces, and these cooling effects reduce in distance away from the green space [18]. The data-driven model cited above evaluated the microclimate regulation related to UGIs in 601 European cities and calculated that at least 16% tree cover was required to achieve a reduction of 1 °C in average urban air temperature [56].

METHODOLOGY

All air temperature sensors were deployed in Stevenson Shields to ensure that the air temperature measured was unaffected by solar radiation. The Stevenson Shields were attached to either road signs or hung from trees, the installation site were all agreed with Leeds City Council. Initially there were 20 sites involved in the first stage of the monitoring that is reported in this paper. However, data from 3 of the urban sensors was lost; 2 of them were removed as part of local council works and not retrieved, the other suffered a sensor failure. The relative locations of the urban sensors and the rural reference sites are shown in Figures 1 and 2. Figure 3 shows example images for 4 of the sensors in urban locations. The UGIs monitored in this work were very small park areas, sometimes described as ‘pocket parks’ [54]. The two rural reference sites were to the North West (NW) and North East (NE) of the city. It is important to note that the selection of monitoring sites was directly influenced by the ownership of the existing assets that the sensors were attached to. In the case of the urban sites, Leeds City Council allowed use of trees and road signs only. Mounting sensors on streetlamps would have allowed for a wider distribution of sensors in grey spaces but these were owned and maintained by a third party and therefore unavailable for this work. Air temperature was measured at hourly intervals throughout the monitoring period of 11th July 2019 to 12th November 2020. The start and end date to this monitoring period was arbitrary to some extent and relates solely to the available time for the authors to install and subsequently download data for all sensors.

All but one of the monitoring sites used Bluetooth enabled air temperature sensors with an accuracy of +/- 0.3 °C [57]. The rural reference site to the North East of the city was located in a private garden. Data for the reference site to the North West of the city was obtained through a public dataset administered by the National Centers for Environmental Information and was logged at the Leeds Bradford Airport site [58]. It is important to note the elevation of Leeds city centre and the respective rural sites as air temperature will gradually decrease as altitude increases [21]. The nominal centre of Leeds (Leeds City Hall) is approximately 58 metres above sea level, compared to an elevation of 116 metres at the North-Eastern reference site and 210 metres at the North-Western reference site.

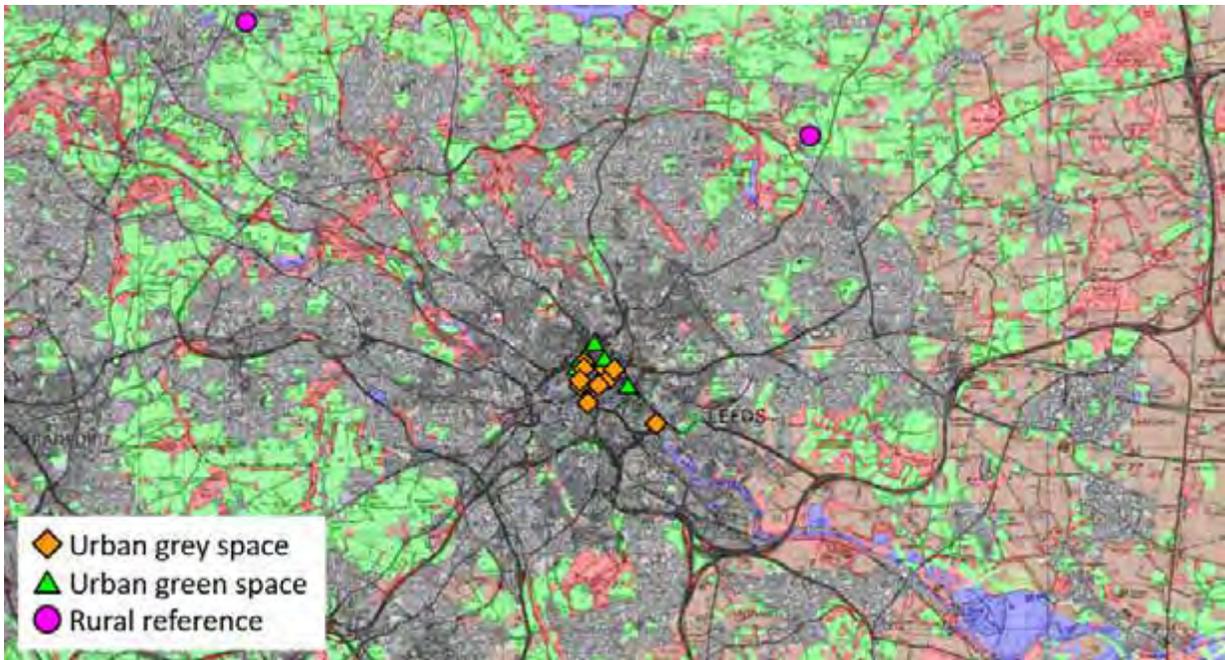


Figure 1. Urban and rural sensor locations
 (Contains OS data © Crown copyright and database rights 2020 Ordnance Survey [100025252])

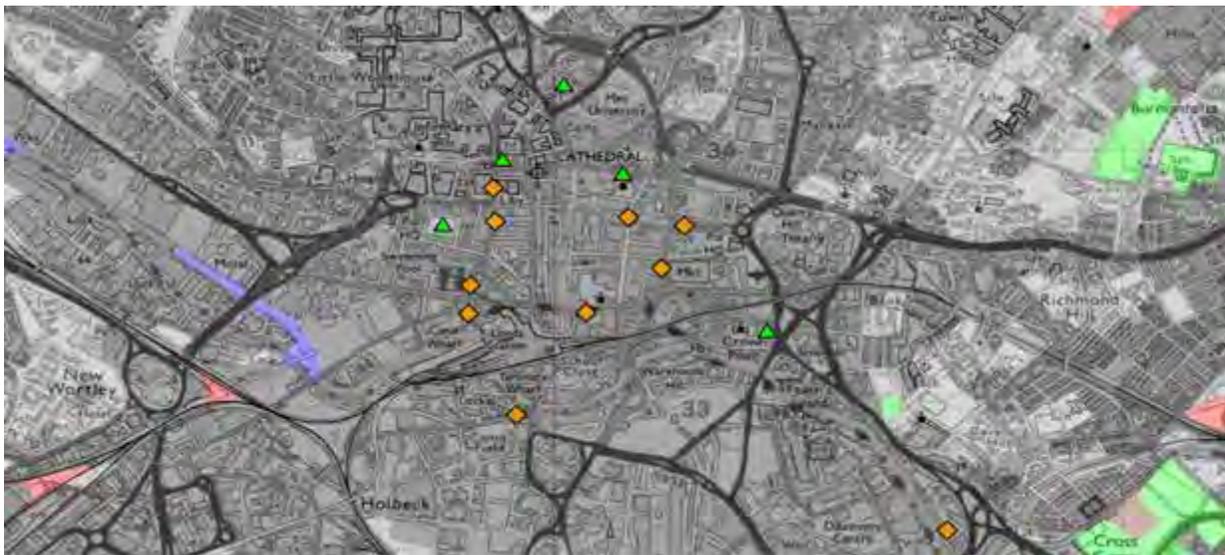


Figure 2. City centre sensor locations
 (Contains OS data © Crown copyright and database rights 2020 Ordnance Survey [100025252])



Figure 3. Example of sensor installation sites in grey and green spaces

RESULTS AND DISCUSSION

Leeds urban heat island July 2019–November 2020

The average diurnal air temperature profile for the urban and rural sites is shown in Figure 4. Although the difference between the urban and rural average temperature does differ from hour to hour, this is not particularly pronounced in terms of changes between daylight and night-time temperature as reported in the literature. Differences between day and night-time air temperature are more visible in Figure 5 which illustrates the hourly UHI intensity (UHII) for urban temperatures when compared with an average value for the rural reference sites, and with both sites individually. The UHII is calculated by subtracting the rural reference site temperatures from those measured at the same time at the urban site.

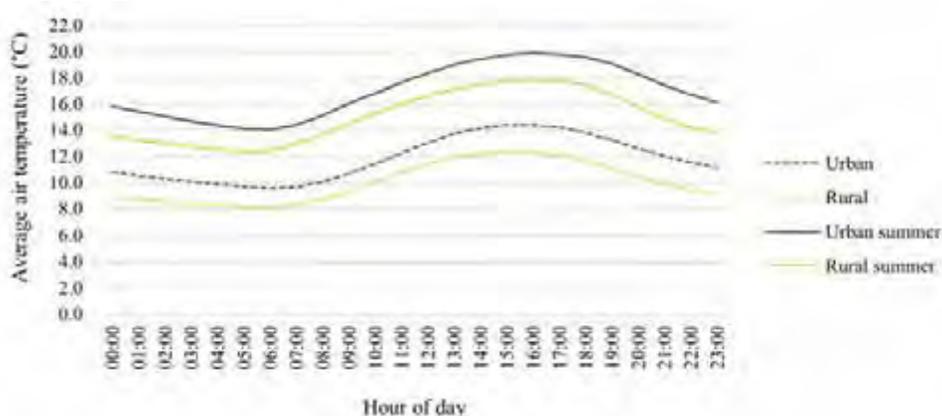


Figure 4. Average hourly air temperature at urban and rural reference sites for Leeds July 2019 – November 2020

The average UHII for the monitoring period was 1.8 °C, the peak average UHII was 2.2 °C occurring at 20:00, and the lowest average UHII was 1.3 °C occurring at 08:00. The peak value for the North-Western site at a higher elevation was 2.7 °C occurring at 17:00 compared with a value of 2 °C at 21:00 for the lower North-Eastern site. The difference between the urban and rural datasets was evaluated by independent t-test, with results suggesting a statistically significant difference between the two datasets ($t(22,421) = 25.69, p < 0.01$).

The peak UHII compared with both reference sites was 4.9 °C at 21:00 on the 24th August 2019. Significance of the rural reference site selection is emphasised when comparing summer peaks in UHII. The peak value compared with the North-Western site was 6.2 °C at 15:00 on 9th August 2019; the peak at the North-Eastern site was 5 °C at 22:00 on 24th August 2019. The average UHII is comparable with data reported in the literature for other cities in the UK, although the peak UHII is approximately 2 °C lower than found in Birmingham, and 3 °C lower than the measured peaks in both London and Manchester.

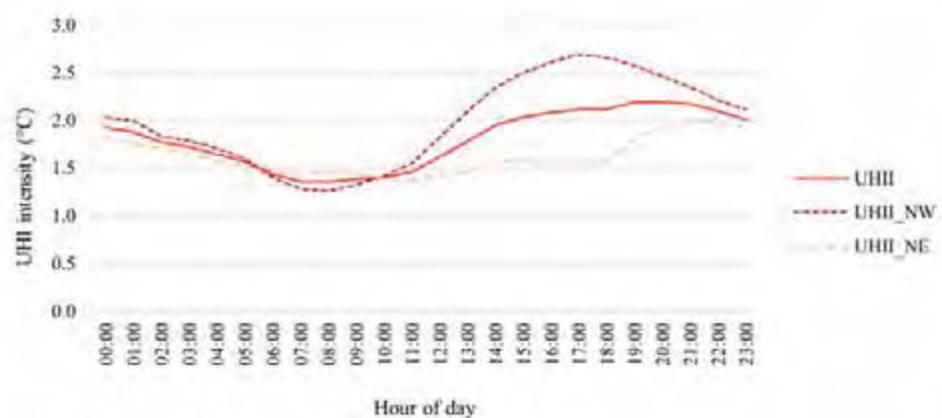


Figure 5. Average hourly UHI intensity for Leeds July 2019 – November 2020

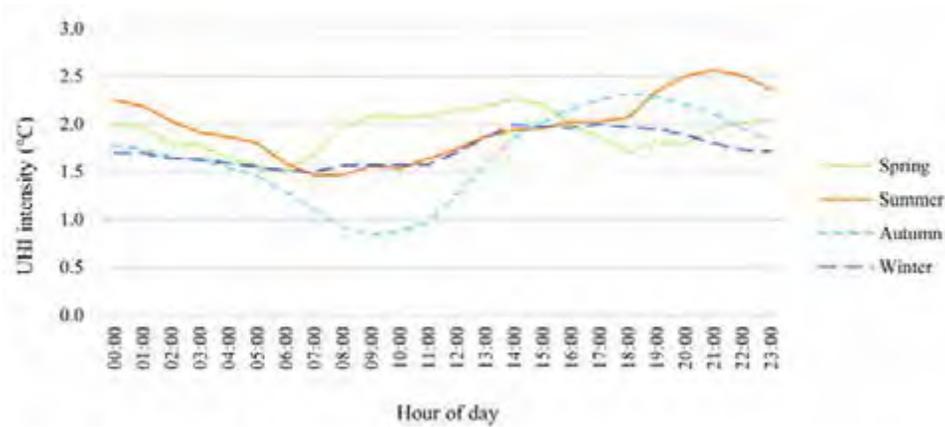


Figure 6. Average seasonal hourly UHI intensity for Leeds July 2019 – November 2020

Seasonal variations for the average UHI are illustrated in Figure 6. Although there is a notable difference between the seasons, the magnitude of the average value is relatively consistent between the seasons. The Summer daily average UHI is 2 °C, for Spring it is 1.9 °C, for Autumn it is 1.6 °C, and for Winter it is 1.7 °C. Times at which the peak hourly average values occur are generally intuitive in the context of the duration and intensity of solar insolation, the Winter peak of 2 °C occurs at 14:00, the Autumn peak of 2.3 °C at 18:00 and the Summer peak of 2.6 °C at 21:00. However, the peak for the Spring average in this dataset occurs at the same time as the Winter peak, 14:00; as only one Spring season is captured in this dataset, further analysis is required to understand if this profile is unique to the monitoring period or a recurring pattern related to natural processes at this time of year.

Urban green space temperature in Leeds city centre

Seasonal diurnal profiles for the difference between green and grey space temperature (Delta T – ΔT) are illustrated in Figure 7. Average ΔT in the green spaces was -0.3 °C during the monitoring period, which fell slightly to -0.4 °C in Summer months. An independent t-test was again used to evaluate these data and returned results suggesting a statistically significant difference ($t(22,434) = 3.742, p = <0.01$). The ΔT values are consistent to those reported for Glasgow in the UK [55] but significantly lower than the ΔT of the large park areas in London [17]. Lower ΔT values during the daytime than during the night are also consistent with values reported in the literature. For all seasons, the lowest ΔT occur in mid-afternoon, the average value in the Summer months was -0.6 °C at 15:00. There is a significant reverse in the average late morning ΔT during Spring and Summer. This is most pronounced for Spring months with a positive average ΔT of approximately 0.3 °C occurring at 10:00. It is not possible to conclude reasons for this from the data alone although some warming effects during Spring and Summer months have been reported in other work [53]. As mentioned previously, there is only one Spring period captured in this dataset. Further work is required to investigate this phenomenon over future years.

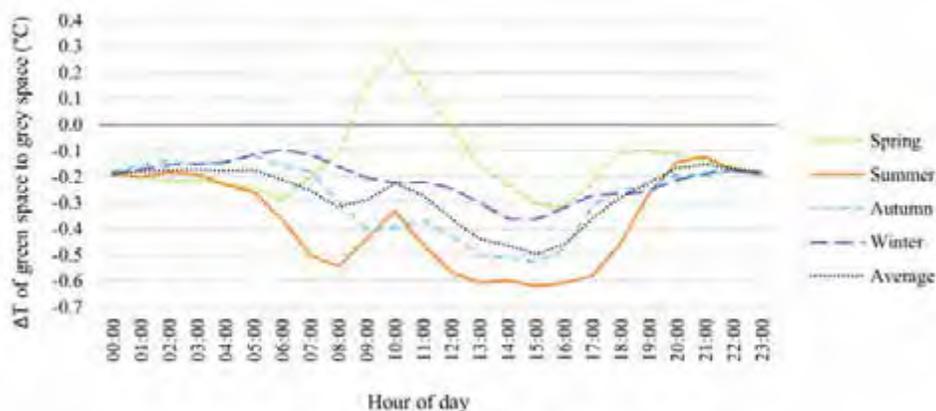


Figure 7. Average seasonal difference between hourly green and grey space air temperature for Leeds July 2019 – November 2020

Although average hourly ΔT values are relatively small, the differences on some of the hottest days can be more extreme. Hourly ΔT profiles for the four hottest days are visualised in Figure 8, along with the average hourly profile for the warmest month in the dataset, August 2020. Nocturnal ΔT values are relatively low in all these examples and reach positive values at some point during the day in all examples. In some cases, trees in particular can restrict air movement that can increase rather than decrease air temperature [53]; further work and measurement of additional variables (such as wind speed and direction) is required to understand whether this is the case for Leeds. Daytime ΔT values reach much lower values on both 30th July 2020 and 12th August 2020, down to $-1.8\text{ }^{\circ}\text{C}$ at midday on the 30th July and $-2.5\text{ }^{\circ}\text{C}$ on 12th August. The ΔT between 08:00 and 18:00 for August 2020 is consistently between $-0.5\text{ }^{\circ}\text{C}$ and $-1\text{ }^{\circ}\text{C}$, at a mean value of $-0.8\text{ }^{\circ}\text{C}$. This suggests that the UGI often help to reduce air temperature in isolated areas.

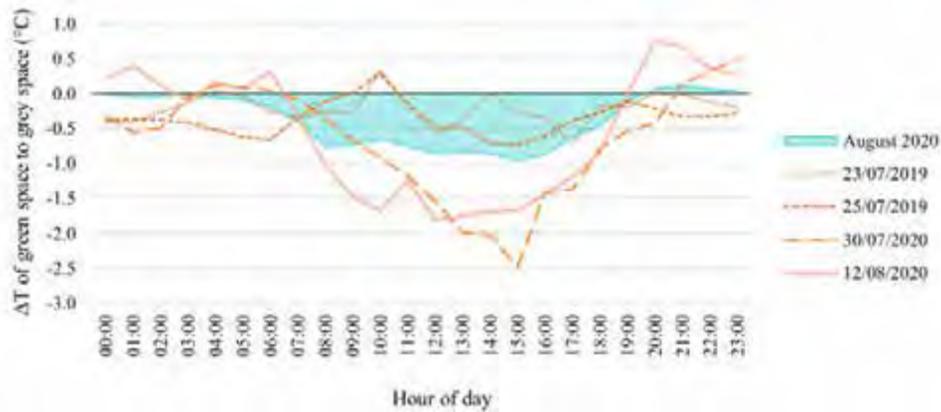


Figure 8. Difference between hourly green and grey space air temperature for Leeds on selected dates July 2019 – November 2020

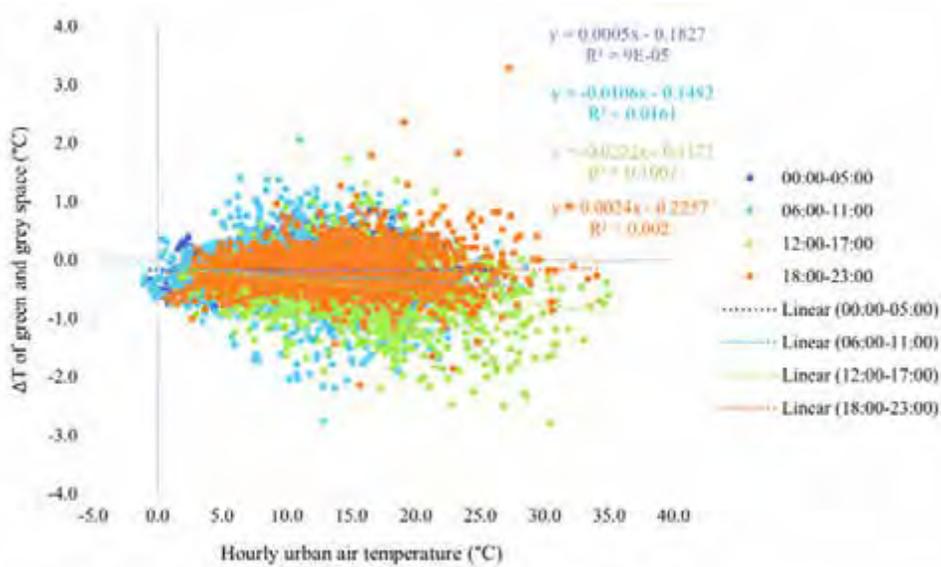


Figure 9. Hourly difference in green and grey space air temperature in the context of average city centre air temperature for Leeds July 2019 – November 2020

Analysis of the data suggests that there are relatively consistent lower temperatures in the UGIs than in the grey areas of the city. However, there is not a strong linear relationship between city centre air temperature and reduced temperatures, as can be seen from data presented in Figure 9. In this chart, the hourly ΔT for the UGI has been plotted against the average air temperature in the city centre. The r^2 values show that the relationship between these values is very weak, meaning that the ΔT for UGI cannot be reliably predicted based upon the urban air temperature alone, regardless of the period of day considered. Despite this weak statistical relationship, the majority of hourly ΔT values are below zero. Across the full monitoring period, 85.22% of hours had a negative ΔT , this reduces slightly during winter months only, to 84.58%. However, when categorised into periods of the day,

the ΔT is below zero for 82.3% of the hours 00:00-05:00, 82.66% of hours between 06:00-11:00, 93.04% between 12:00-17:00, and 82.87% between 18:00-23:00. For the Summer months, nocturnal hours decrease slightly (79.31% between 00:00-05:00 and 74.86% between 18:00-23:00) but daytime hours with a ΔT below zero increase to 88.61% between 06:00-11:00 and 95.56% between 12:00-17:00. This suggests that the UGI provide a potentially useful cooling effect when air temperatures are at their hottest during the day but are not as effective during the nocturnal hours when the average UHII is at its highest.

CONCLUSION

A high-resolution hourly dataset for the Leeds UHI and UGI air temperatures has been discussed in this paper, covering the period July 2019 to November 2020. The average UHI intensity during the monitoring period was 1.8 °C which is consistent with other cities in the UK, although the peak UHII was approximately 2 °C lower than that measured in other UK cities. The diurnal pattern of the UHII for Leeds during this monitoring period was found to be similar to other cities, in that it is higher during nocturnal hours, although these differences were not as pronounced in this dataset as they are in other examples from the literature. There is a relatively small proportion of green space in Leeds city centre but the small areas of UGI were still an average of 0.3 °C cooler than the surrounding grey space, and 0.4 °C lower during Summer months; this can reach a peak of up to 2.5 °C cooler during the hottest days of summer months. The majority of hourly air temperature in UGI were lower than the surrounding grey spaces, suggesting that these spaces can provide some relief from high summer temperatures for the city's residents. However, air temperature in the surrounding rural areas is still significantly lower than those found in the UGI. Although the UGI leads to localised reductions in air temperature, existing literature indicates that this is unlikely to have a significant impact on the city centre UHII due to the very small proportion of existing green space.

The work presented here was limited by the relatively small number of sites with available data within the city centre. Further work has been designed to address this; new sensors were installed in April 2021 to extend this network to include 70 air temperature and relative humidity sensors across the Leeds city region. A total of 20 sensors are now installed in the city centre, with the remainder installed at 1.5 km intervals (up to 6 km from the centre) along the 8 cardinal and ordinal directions. Wherever possible, sensors have been paired to monitor green and grey space at each point. Future work will also aim to include additional relevant variables in the analysis, especially wind speed and direction data. Analysis of future data will aim to understand reasons for the higher temperatures measured in the UGI at specific times, especially those reoccurring at mid-morning during spring and summer months.

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HOLZBAU-GIS: PRESENTING FIRST RESULTS OF GIS-BASED MODELLING ON REDUCTION OF GREENHOUSE GAS EMISSIONS, THROUGH CONSTRUCTING AND RENOVATING WITH TIMBER, ON A MUNICIPAL LEVEL

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ABSTRACT

The German government has formulated ambitious climate protection targets for the building sector up to the year 2045 and beyond. [1 - 3] Municipalities can play a significant role in the implementation of these targets. By acting responsibly, they can have a direct impact on regional urban development, especially with the focus on climate mitigation and climate adaptation. [1]

A key element of municipal climate protection is the building sector. In particular, wooden structures designed for durability and reusability can support the reduction of GHG emissions in municipalities. [4, 5] Municipal decision-makers are, however, usually unaware of these potentials. This is where the implementation of a geodata-based web-GIS system “Holzbau-GIS” can be useful. The aim of the R&D project “Holzbau-GIS” is to demonstrate the potential use of wooden building materials as an additional climate protection measure, on a municipal level.

This paper describes the methodology used to calculate GHG reduction potentials and their visualisation in a web-GIS system. The web-GIS system is based on available geodata at the building level and contextualizes the results of the GHG calculation on a municipality-wide context. Realizable reduction potentials for new timber constructions or refurbishment measurements of existing buildings can be projected in different scenarios. The results can be divided into two categories; carbon storage of the renewable wooden building material and the GHG reduction potential by replacing mineral structures with wooden structures.

KEYWORDS

Municipal Climate Protection; Web-GIS System; Timber Construction; GHG Reduction

INTRODUCTION

Following the Paris Agreement and the resulting Law on Climate Protection, the German government is currently pursuing the goal of achieving greenhouse gas neutrality by 2045, as well as an “almost climate-neutral” building sector. [1 - 3, 6] The building sector in Germany is accountable for 35 % of final energy consumption, around one third of greenhouse gas (GHG) emissions. [3, 4] For the building sector, the German government is aiming for a 66-67% reduction in GHG emissions (compared to 1990) by 2030. [1, 7] Therefore, an important measure is the reduction of environmental emissions along the life cycle of buildings. [4]

Municipal level

It is not usual to handle climate protection measurements as a task of self-government, like urban land use planning or the management of municipal properties. However, many climate protection measures require action at the regional and local level. [1]

Regarding the building sector, the government must identify the use of renewable materials as a climate- and environmentally friendly alternative in order to reduce the consumption of limited resources. In public building projects and their tendering, environmental aspects must be given greater prominence. The effects of GHG reduction and energy saving in the construction and deconstruction of buildings are relevant. [8]

Suitable timber construction can be used in all areas of municipal buildings. In addition to the renovation of existing infrastructure facilities, there is an increasing demand for new buildings of municipal and social infrastructure. Timber constructions are available for buildings such as offices, kindergartens, schools and universities, museums and libraries, as well as buildings for various sports. Various timber constructions are well suited for industrial, commercial or agricultural buildings, too. [9, 10]

However, municipal decision-makers are usually unaware of these potentials as part of the urban planning, but the municipal authorities and local government play an essential role in implementing this process. They have a significant direct impact on the regional urban development regarding climate protection and climate adaptation through active actions. [1] This is where the web-based geographic information system (GIS) “Holzbau-GIS” (timber construction-GIS) can be useful.

HOLZBAU-GIS

The aim of the R&D project “Holzbau-GIS” is to demonstrate the potential of utilizing wooden building materials as an additional climate protection measure for municipalities and to make this nature-based solution practicable.

Figure 1 shows the general developed method. The Geodata-Management Tool is used to classify the building level based on available geodata. The GHG-Calculator defines the reduction potential by replacing mineral constructions with timber constructions. The Scenario-Manager defines the total amount of saved GHG emissions.



Figure 1: Methodical structure of the web-GIS system “Holzbau-GIS”

The “Holzbau-GIS” is being applied on the municipal level. The web-GIS system is based on available geodata at the building level and sets the results of the GHG calculation into a municipal-wide context. Various country-wide available municipal geodata (development plans, building footprints, building types, building functionalities, 3D building models, historical satellite images, etc.) are used to set up a geodatabase in order to provide a solid starting point for the GHG calculation by the research partner Environmental Engineering+Ecology (eE+E).

Based on this, the research partner Resource efficient Building (ReB) calculates the GHG reduction potentials that are the focus of this article. Both the geodata management and the development of the method for calculating the GHG reduction potentials enable the derivation of various scenarios for new constructions or refurbishment measurements. The results are divided into the carbon storage in the wooden material and the GHG reduction potential by replacing mineral constructions with wooden structures.

The system architecture of the web-GIS system is a client-server application using the Cadenza business intelligence and geo-analytics platform [11] by the research partner Disy Informationssysteme GmbH (disy). The geodatabase is primarily a PostgreSQL database management system with the extension “postgis” for managing geodata. The output of the GIS-model is transferred into the database via an Extract Transform Load [12] process. Additional geodata in the context of urban development is also stored in the database or directly accessed as a third-party web service, e.g. background maps. The database is also used for the operation of the Cadenza platform, which includes configuration, user management and logging. The web application is running as a Java Servlet in an Apache Tomcat web server and can be accessed with any modern web browser as client.

The user interface of Cadenza offers the visualization and analysis of the model results. The data can be filtered and displayed as interactive tables and diagrams or rendered in map views. For analytics, the Online Analytical Processing [12] approach is used, which allows analysis of multidimensional data on different spatial and temporal scales. A combined presentation is available in a dashboard which allows the simultaneous visualization of the same data in different views. Depending on the rights defined in the user management, the user can create an individual analysis to gain more explorative insights from the model results.

NEW CONSTRUCTION SCENARIO

Data basis

This paper presents first results according to the scenario “new construction”. The scenario quantifies the GHG reduction potential using wooden materials for the building construction instead of mineral materials. The potential can be calculated for residential and non-residential building types. Figure 2 provides an overview of the data basis and the distinctions in usable building types. Furthermore, Figure 2 contains the different values resulting from the data basis and the corresponding unit. Finally, the application of the individual building data to the municipal level is implemented.

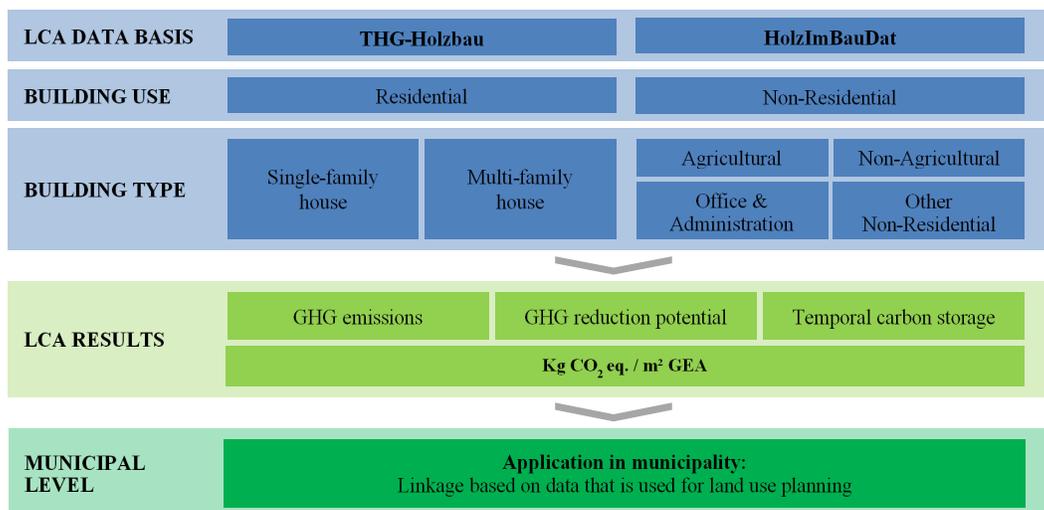


Figure 2: Data basis and distinctions of the “new construction” scenario

Content of former research projects “THG-Holzbau” and “HolzImBauDat” [13, 14], in detail lifecycle assessments (LCA) of various buildings, are operating as the general data basis for this scenario. The buildings studied there represent the German building stock and were built following the European standards (EN 15978), the German state-of-the-art, and were accompanied by an external review. [5]

For residential buildings, a distinction is made between single-family houses (SFH) and multi-family houses (MFH). Additionally, there are four different types of non-residential buildings: agricultural buildings (ST), non-agricultural buildings (HA), office and administration buildings (OB) and other non-residential buildings (SN). Agricultural buildings mainly include stables and facilities for farm animals. Non-agricultural buildings mainly include commercial and industrial halls and warehouses.

The “new construction” scenario contains three different values for each building type named. Each value is given in kg CO₂ eq./m² gross external area (GEA):

1. Average GHG emissions of the whole lifecycle for all wooden buildings and all mineral buildings separately
2. Average GHG reduction potential of the whole lifecycle for wooden variants compared to the corresponding mineral equivalents
3. Average carbon storage of the whole lifecycle for all wooden buildings and all mineral buildings separately

New construction projects are handled on a municipal level within the framework of communal urban land use planning. This mechanism is considered as the key reference to link the calculated GHG reduction potentials on a building level. In detail, one purpose of the research project is to identify connection points in communal urban land use planning that can link to the LCA data basis.

Case studies

The “new construction” scenario needs data for calculating the potential GHG savings that are usually not yet available. Therefore, it is necessary to establish the calculations in the project on the basis of case studies. The city of Menden serves as an example municipality in the research project.

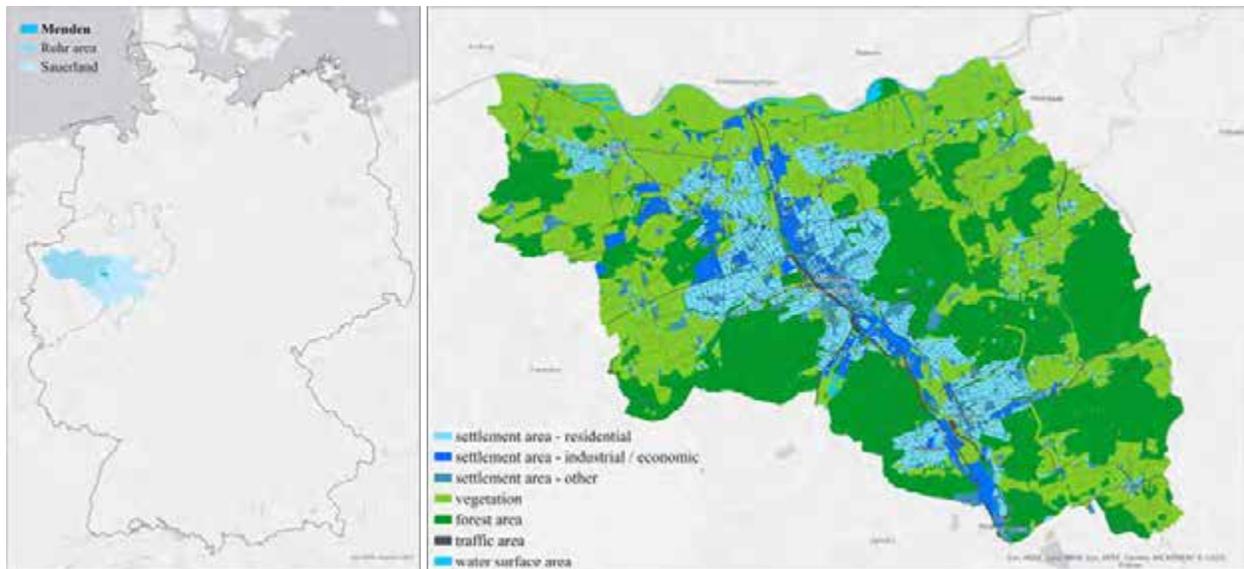


Figure 3: Geographical location of Menden, within Germany, and the current spatial utilization of the area

The geographical location of Menden within Germany is shown in Figure 3. Menden is located in the northern part of the region Sauerland as well as on the eastern edge of the Ruhr area and belongs to the district Märkischer Kreis. Menden has a total of 20 city districts, ranging from historically grown village structures to rural settlement structures. [15] The area of Menden covers 86.10 km² and has a population density of 609.2 inhabitants per km² with a total of 52 452 inhabitants (reference date: 31.12.2020). Figure 3 displays the utilization of the area of Menden according to the following values (reference date: 31.12.2020): [16]

- 16.39 km² settlement area
 - of which 9.11 km² residential area
 - of which 3.56 km² industrial and economic area
- 64.03 km² vegetation
 - of which 32.05 km² forest area
 - of which 30.52 km² agricultural area
- 4.69 km² traffic area
- 0.98 km² surface water area

For the case studies, development plans have been identified as connection points in communal urban land use planning and the LCA data basis. Based on new construction projects of the municipality Menden between 2016 and 2021, GHG reduction potentials are calculated and visualized in the “Holzbau-GIS”. For this purpose, the published development plans of Menden [17] of the last five years are used. As a first step, the available development plans were georeferenced and the corresponding areas and data of the plan were digitalized. This results in the selection of the six following development plans for the exemplary representation of the new construction scenario. The constructible land area of each project and its location in Menden is shown in the following Figure 4:

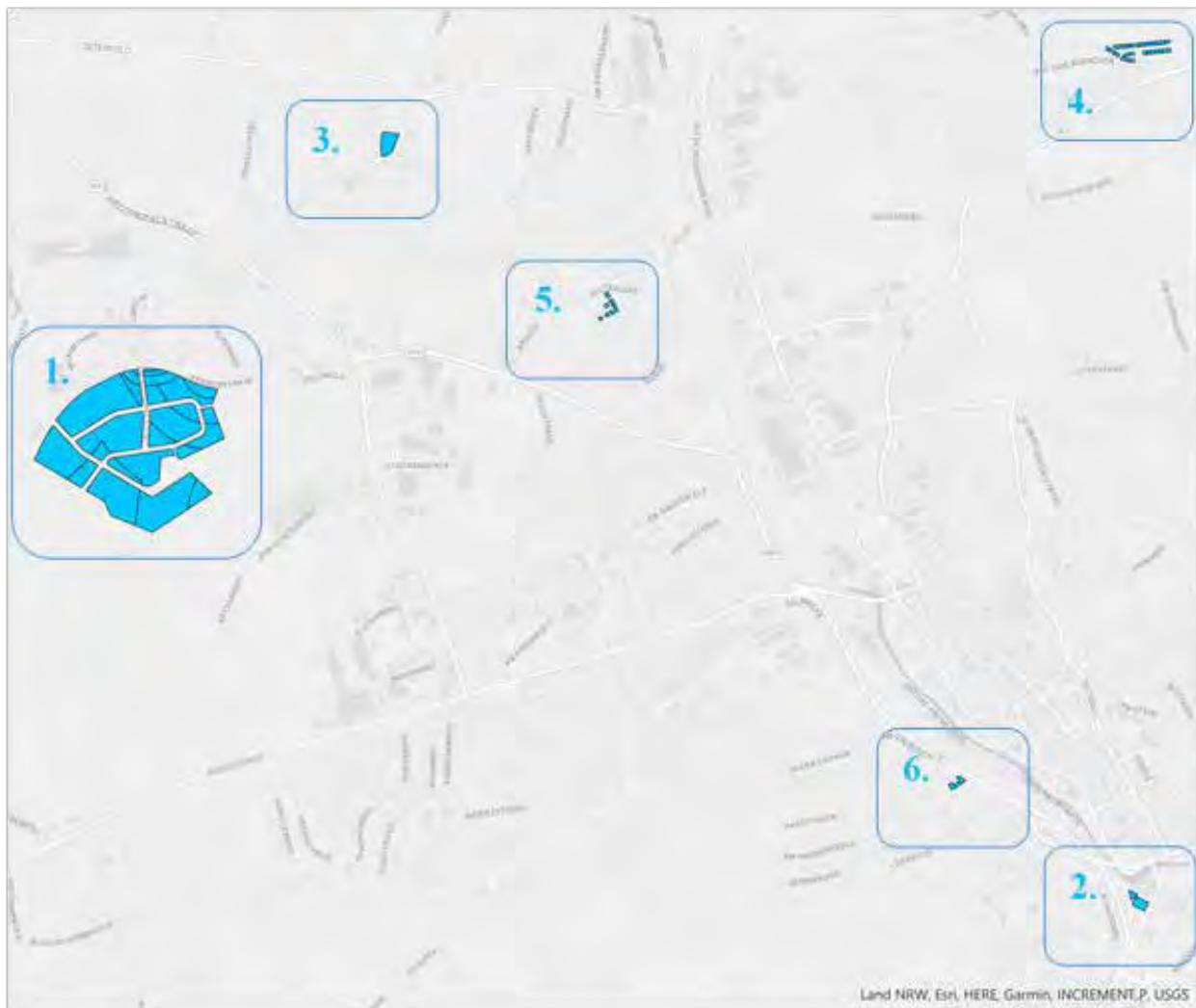
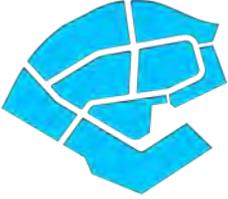
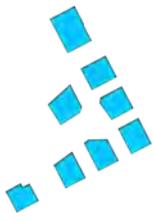
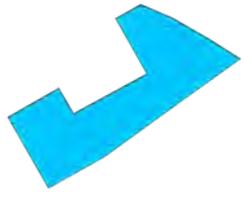


Figure 4: Overview development plan case studies

Table I describes each development plan in more detail, the enactment year and the size of the constructible land area is given. Additionally, Table I contains details of the permitted land usage and building type. This information is relevant for the intended calculations.

Table I: Overview development plan case studies

| | |
|---|--|
| <p>1.</p>  | <p>Plan No.: 205</p> <p>Enactment: 2019 Constructible land area: 281109.8 m² Type of land usage: economic area / industrial area Type of building usage: non-residential Building types: non-agricultural</p> |
| <p>2.</p>  | <p>Plan No.: 210</p> <p>Enactment: 2020 Constructible land area: 6680.7 m² Type of land usage: economic area / special area Type of building usage: non-residential Building types: non-agricultural / office and administration</p> |
| <p>3.</p>  | <p>Plan No.: 211</p> <p>Enactment: 2016 Constructible land area: 5631.9 m² Type of land usage: residential area Type of building usage: residential Building types: single-family house</p> |
| <p>4.</p>  | <p>Plan No.: 217</p> <p>Enactment: 2017 Constructible land area: 13783.7 m² Type of land usage: residential area Type of building usage: residential Building types: single-family house</p> |
| <p>5.</p>  | <p>Plan No.: 221</p> <p>Enactment: 2018 Constructible land area: 3996.9 m² Type of land usage: residential area Type of building usage: residential Building types: single-family house</p> |
| <p>6.</p>  | <p>Plan No.: 226</p> <p>Enactment: 2019 Constructible land area: 1911.9 m² Type of land usage: residential area Type of building usage: residential Building types: single-family house / multi-family house</p> |

Parameters

In addition to the land usage and building type, further values can be taken from the development plans. The values are determined by various federal and state laws and regulations [18 - 20]:

- Constructible land area (CLA) – see Table I
- Building floor area (BFA) – see Figure 5
- Gross external area (GEA) – see Figure 6
- Gross volume (GRV) – see Figure 7
- Ground space index (GSI) –see Eq. 1
- Floor space index (FSI) – see Eq. 2
- Cubic index (CI) – see Eq. 3
- Maximum number of apartments
- Maximum number of entire storeys (ES)
- Maximum ridge height (RH)

The constructible land area (CLA), as given in Table I, represents the available building area excluding areas to be charged with rights of way, green areas, water areas and waterways. The building floor area (BFA) is the area at which the building stands on the property. It is the so-called “footprint” of the building. Gross external area (GEA) is the total area of all floors, vertical surfaces and ceilings of a building across all floors. Gross volume (GRV) is the total volume of all of a building’s interior spaces over its total floors. This volume is defined by the exterior boundary surfaces of the building’s foundation, exterior walls and roof. [21]

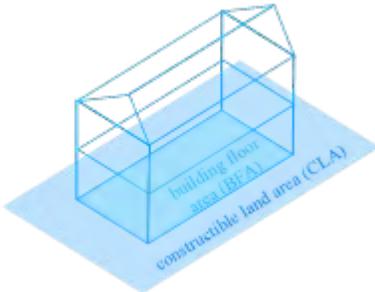


Figure 5: schematic depiction of GSI, BFA, CLA [22]

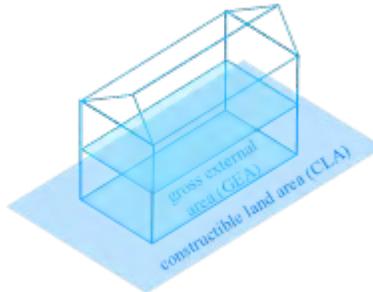


Figure 6: schematic depiction of FSI, GEA, CLA [23]

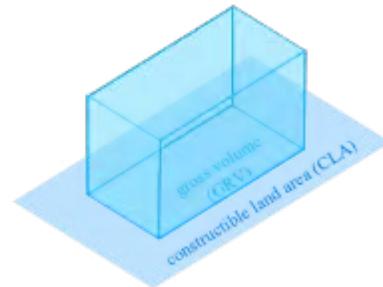


Figure 7: schematic depiction of CI, GRV, CLA [24]

| | | | | | |
|-------------------|---------|-------------------|---------|------------------|---------|
| $GSI = BFA / CLA$ | (Eq. 1) | $FSI = GEA / CLA$ | (Eq. 2) | $CI = GRV / CLA$ | (Eq. 3) |
| $BFA = GSI * CLA$ | (Eq. 4) | $GEA = FSI * CLA$ | (Eq. 5) | $GRV = CI * CLA$ | (Eq. 6) |

The ground space index (GSI) is the ratio of BFA to CLA (Eq. 1). This value indicates the maximum permitted BFA for each CLA in the development plan (Eq. 4).

- The floor space index (FSI) is the ratio of GEA to CLA (Eq. 2). This value is used to determine the maximum permitted GEA of a construction within the development plan (Eq. 5).
- The cubic index (CI) reflects the ratio of GRV to CLA (Eq. 3). This value defines the maximum permitted GRV of a construction within the development plan (Eq. 6). The CI is mainly given for non-residential buildings.

Additional parameters like the maximum numbers of apartments, entire storeys and ridge height are either useful to identify the type of building or, if the previous values are not given, still to conclude on the necessary data.

Calculations

Due to varying information, different approaches are necessary to calculate the required linkable parameter. The aim of the approach is to calculate the GEA for the selected CLA using the legally regulated data of the development plan. All calculations refer to the maximum permitted GEA. Table II shows the method for calculating the maximum permitted GEA for the individual CLA of the case studies. In all cases, the CLA is taken from the development plan. The GSI is also given for all case studies. It is used to calculate the maximum permitted BFA. If the FSI is also given, the maximum permitted GEA can be calculated without much effort. If the FSI is not determined, other parameters must be considered. Alternatively, the maximum permitted GEA can be calculated by multiplying the number of entire storeys (ES) with the BFA. The number of entire storeys can be derived from the maximum ridge height (RH). If details are still missing for calculations, assumptions have been made in individual cases.

Table II: Overview of the derivation of GEA for each development plan

| Plan No.: | 205 | 205 | 210 | 210 | 211 | 217 | 221 | 226 |
|-----------------------|---|---------|---------|---------|---------|---------|---------|---------|
| GEA [m ²] | FSI*CLA | ES*BFA | ES*BFA | ES*BFA | FSI*CLA | ES*BFA | FSI*CLA | FSI*CLA |
| BFA [m ²] | GSI*CLA | GSI*CLA | GSI*CLA | GSI*CLA | GSI*CLA | GSI*CLA | GSI*CLA | GSI*CLA |
| CLA [m ²] | Construction boundaries as specified in each development plan | | | | | | | |
| entire storeys (ES) | | | RH | ES = 1* | | RH | | |

*(Assumption)

Limitations and assumptions

- General: If the number of entire storeys is less equal 2, then the residential building is constructed as a single-family house. If the number of entire storeys is greater than 2, then a multi-family house is built instead.
- Plan No. 226: The construction of MFH is assumed, as there are no restrictions of a maximum number of entire storeys for this construction field.
- Plan No. 210: For the special area, it is assumed that the extension will not be carried out, instead a larger hall will be newly built (HA). For the economic area, it is assumed that it includes office and administrative buildings (OB).

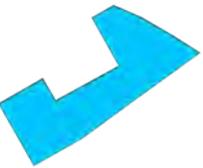
RESULTS

Preconditions of the following results are these assumptions. Firstly, it is assumed that the maximum permissible GEA is fully exploited and realized constructively. Secondly, the construction of the new buildings is completely and exclusively converted to timber construction instead of conventional materials. The functionality of the buildings is always ensured and remains unchanged.

Using the LCA data of the research projects “THG-Holzbau” [13] and “HolzImBauDat” [14] for the various building types, the GHG reduction potential can be calculated. Table III shows the categorization of the six development plans into the different building types. Furthermore, the results of the GHG reduction potential are shown. In addition, the temporary carbon storages for the different construction materials are presented.

The six development plans have different land uses and building types. Three sites are planned as non-agricultural buildings (HA), and four others as single-family houses (SFH). Moreover, there is one site to be developed as office and administration buildings (OB) and another site as multi-family houses (MFH).

Table III: Overview of usages, GHG reduction potential and carbon storage for the development plans

| | Land usage | Building type | GHG reduction potential [t CO ₂ -Eq.] | Carbon storage Timber construction [t CO ₂ -Eq.] | Carbon storage Conventional construction [t CO ₂ -Eq.] |
|---|------------------|---------------|--|---|---|
|  | economic area | HA | 20934.24 | 28360.54 | 4874.29 |
| | industrial area | HA | 16560.29 | 23978.31 | 4121.12 |
|  | special area | HA* | 157.09 | 227.45 | 39.09 |
| | economic area | OB* | 308.80 | 577.52 | 99.26 |
|  | residential area | SFH | 525.98 | 824.11 | 108.54 |
|  | residential area | SFH | 965.47 | 1512.71 | 199.23 |
|  | residential area | SFH | 373.27 | 584.85 | 77.03 |
|  | residential area | SFH | 108.39 | 169.83 | 22.37 |
| | residential area | MFH* | 48.59 | 99.48 | 2.70 |

*(Assumption)

The GHG reduction potential ranges from 49 to 20 935 t CO₂ equivalents, with a total possible reduction of 39 982 t CO₂ equivalents. The GHG reduction potential describes the savings of GHG emissions if the building is built with a wooden material instead of mineral materials. The reduction arises from the environmental benefit of renewable materials over their entire life cycle. It can be seen from the data in Table III that the HA reported significantly more GHG reduction potential than the other types. The results indicate that the higher amount of GHG reduction is only caused by the larger constructible land area, but even down to m², the highest potential lies here. The reason for this could be the higher GSI for non-agricultural buildings in contrast to residential buildings.

The carbon storage ranges from 100 to 28 361 t CO₂ equivalents using timber as building construction. If conventional building constructions are chosen, the carbon storage ranges from 3 to 4 875 t CO₂ equivalents. In total, a carbon storage of 58 286 t CO₂ equivalents can be temporarily stored, if the maximum permitted GEA is realized with renewable materials and still an amount of 9 879 t CO₂ equivalents, if mineral constructions were chosen. From this data, it is seen that the carbon storage (conventional) for the MFH resulted in the lowest value of 2.70 t CO₂ equivalents. Based on the carbon storage in timber construction, the storage (conventional) will be 2% of the possible storage potential for this building type. In contrast, no significant differences were found between HA, OB and SFH, where the percentage is higher, around 13-17% of the possible carbon storage. The correlation between building type and carbon storage is interesting because it demonstrates the influence not only of the choice of materials, but also of the chosen building type. For MFH in conventional construction, timber is often used in smaller quantities in relation to the total material mass than in SFH, where the roof structure is mainly built using timber.

Taken together, these results provide important insights into the possibilities of quantifying environmental factors and, as a municipality, integrating this data into its urban land use planning and climate protection concepts.

In order to give an impression of the web-GIS system “Holzbau-GIS”, the preview of development plan no. 226 is given here as a screenshot in Figure 8. The constructible land area of development plan no. 226 is displayed as well as the total GHG reduction potential, subdivided according to the building type.

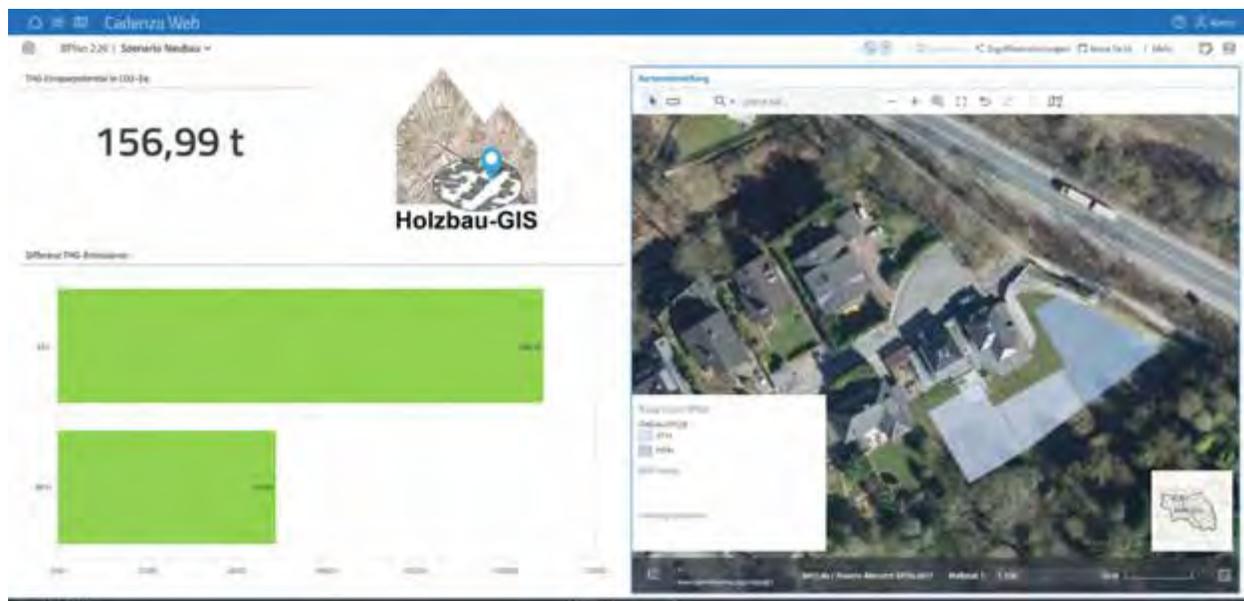


Figure 8: web-GIS system “Holzbau-GIS” showing results of development plan no. 226

CONCLUSIO

The present study was designed to determine the effect of the use of wooden material in the building sector at the municipal level. The web-GIS system “Holzbau-GIS” contributes to this process. Using the example of the city of Menden, GHG reduction potentials for new buildings can be quantified.

In summary, within the “new construction” scenario, there are two levels of consideration: Case studies of already enacted development plans (what could have been...?) and a user interface in the web-GIS system “Holzbau-GIS” for future projects of the municipality. The case studies function as exemplary calculations to show the decision-makers of a municipality the potential of timber constructions. Based on the data from selected development plans, it is possible to determine reference parameters that are needed for the extrapolation. With these examples, the GHG-emissions and reduction potentials are quantified and can be visualized within the web-GIS system. At the moment, six case studies are shown in the “Holzbau-GIS”. By using the interface, users are able to determine data for future new construction projects. Entering the type of land usage, type of building usage and planned building type together with the relevant GEA, the average GHG emissions, average GHG

reduction potential and average carbon storage can be calculated. Both levels of consideration are part of the “Holzbau-GIS”, while this paper focuses exclusively on the case studies.

The scope of this study, and also other calculations determined in the web-GIS system “Holzbau-GIS”, is limited in terms of the accuracy of the individual building. The calculations refer to average values for standardised building types. In each individual case, a further examination by using a comprehensive life cycle assessment is required to obtain GHG savings for the exact building. The current data highlights the importance of a valid extrapolation to provide a first estimate of the potential GHG reduction.

This data can be used as a basis for municipal decisions. In future, parameters like GHG savings will gain importance for applications or funding of municipal projects. Additionally, as proposed in the EU Green deal [25] and the European Bauhaus initiative [26], building with wood will play a major role in climate mitigation for the building sector.

For this purpose, the “Holzbau-GIS” can be a prototype and support municipalities in integrating renewable materials in their building projects as additional measures in their municipal climate protection concept. In a further phase, the research project will focus on the energy-related refurbishment of existing buildings using renewable building materials.

ACKNOWLEDGEMENT

This study was carried out on the basis of the research project “Holzbau-GIS: Reduction of greenhouse gas emissions by building and renovating with wood” funded by the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Waldklimafonds. The authors gratefully acknowledge the assistance of all concerned.

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HEATWAVES AND THEIR IMPACT ON SOY AND MAIZE PRODUCTIVITY USING CPC GLOBAL DATASET IN BRAZILIAN SUBTROPICAL REGION

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ABSTRACT

South America is an important soy and maize (SM) producing region accounting for ~46 and 15% of the world's total harvested area respectively. Production varies due to yearly precipitation and air temperature variability and the fluctuating average temperature considerably affects SM productivity and phenological cycle. This work aims to evaluate heat waves (HW) as the impact of extreme climatic indices on SM phenological development over Brazilian subtropical regions using CPC Global data. For this, a characterization and spatial coverage of heat waves, that is, frequencies, intensity, and persistence, in subtropical Brazil, were performed using available results from the Reis study region available results (34° S to 24.7° S and 57.7° W to 48° W), defined according to their climatic characteristics. Impact estimation was assessed based on a comparison between the total annual average HW calculated from the base period (reference 1979-2005) with the observed total annual SM yield. Results showed 54 heat waves in the study region, based on the 90% percentile of persistence for maximum temperature anomalies from 1980 to 2013. Yields showed year-to-year variabilities from -30%, -27%, and -26% for 1991, 1987, and 2005, the same years for some annual persistence days of HW events. At large, the results show that the subtropical region of Brazil has been affected by increasingly recurrent and assiduous heat waves, together, SM yield annual variability showed to be following the same pattern. Nevertheless, more studies with longer datasets should be assessed to generate general models that can explain yield variability due to HW.

KEYWORDS

Heatwaves; soy and maize; yield productivity; extreme events

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), global average temperatures have increased by 0.85 °C during the 1800 – 2012 period [1] - [3]. This tendency is likely to continue during the 21st century under all Representative Concentration Pathways (RCPs) [1]. These changes in mean temperature can profoundly disrupt social and natural environments [2], [3]. Yet, extreme temperature events such as heat waves (HW), severe winter and summer, hot and cold days, and nights can cause more severe effects on human and agricultural environments [4].

Understanding how HW disturbs agricultural production is critical to preparing communities for HW and assessing the probable impact of HW due to climate change [5]. HW is generally described as extended periods of extreme heat, whereas there is no constant characterization of the temperature threshold, the temperature system of measurement, and the number of days used to delineate HW [6]. Heatwave occurrences are probable to become more recurrent and powerful in the mid-latitudes of the Northern and Southern Hemisphere in the future. Our understanding of the influences of these dangerous temperature events on agroecosystems is still limited [7].

Considerable increases in extreme climatic events in the last decade have opened a frightening gap in the scientific literature on its impacts. Scientifics have concentrated excessively on mean anomalies changes, whereas it is the extremes that provoke common impacts and ecosystem state changes [8] such as yield productivity. The forecast climate changes challenge future agricultural efficiency for most of the cultivated crops, such as maize and soy, and will unveil great yield drop underneath higher temperatures conditions [9].

During the last decades, the changes in climate extremes and their influence on agricultural production have increased the requirement for regional climate projections [10] to provide reliable data for planning and adaptation strategies. Some authors stated that 30-39% yield changes are justified by climate variability, at a global scale, and some areas overpass 60% [11], [12]. South America is noteworthy soy and maize (SM) producing region accounting for around 30% of the world's total collected area [13]. Productivity, however, can vary due to precipitation and temperature anomalies [14].

Taking these aspects into account, the present study aimed to assess whether HW indices were correlated with soy and maize (SM) productivity in the Brazilian subtropical region (BSR).

DATA AND METHODOLOGY

Study Area

Subtropical Brazilian Region (SBR), located in Southern Brazil, and covering most of the Southeastern states and all Southern states was taken as a study area. SBR was divided into two regions, following [15], region 1 (R1) (34°S to 24.7°S and 57.7°W to 48°W) and region 2 (R2) (24.7°S to 20.2°S and 58.3°W to 40.5°W). These two areas presented the most severe maximum temperature (Tmax) anomalies (exceeding 3.5°C) when compared to other Brazilian regions.

Data

The meteorological data used in this study is daily Tmax in Celsius degrees (°C), provided by the Climate Prediction Centre/ National Oceanic and Atmospheric Administration [16] (CPC/ NOAA/OAR/ESRL PSL), with a spatial resolution of 0.50 - degree latitude x 0.50 - degree longitude grid (720x360) from 1980 to 2018 (Fig. 1) (from their web site available at: <https://psl.noaa.gov/data/gridded/data.cpc.globaltemp.html>).

SM crop yield (kg ha⁻¹) data was gathered in freely accessible data from the Brazilian National Supply Company (CONAB), and available regionally including, Mato Grosso, Mato Grosso do Sul, Paraná, Santa Catarina, and the Rio Grande do Sul states, covering R1 and R2. Data were detrended using the *pracma* package for R [17] that computes the least-squares fit of a straight line (or composite line for piecewise linear trends) to the data and subtracts the resulting function from the data.

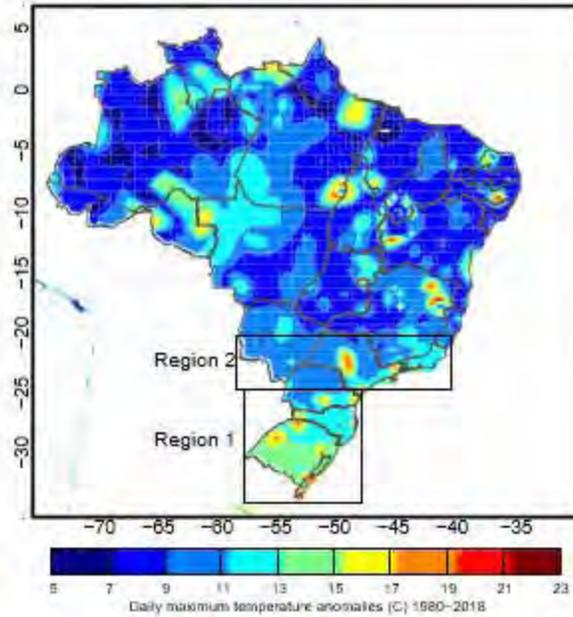


Figure 1. Study area. Rectangles represent southern Brazilian sub-regions.

Heatwave analysis

To define HW during the period selected in this study, the time series of daily Tmax anomalies were calculated separately for each study region. To select the extreme Tmax considering its variability over the year, a 90% percentile (P90) of Tmax anomalies was calculated for each month in regions 1 (R1) and 2 (R2).

To define the minimum persistence necessary to be considered a HW, a monthly P90 was also calculated for the number of consecutive days in which Tmax anomalies remained above their threshold. Thus, whenever Tmax anomalies in each month remained above their threshold, for days that also satisfy the minimum persistence condition for that month, a HW was counted.

After that, a filter was used to match crop planting dates for maize and soybean for each region and calculated HW number and intensity. For growing season data homogenization, planting date was defined to 150 days counting from July 1st and August 15th for maize and soy respectively following CONABs recommendations.

Statistical analysis

Statistical analysis was performed based on a comparison between heatwaves frequency, average number and intensity and detrended productivity [18] data series averaged over each region. To comprehend the correlation between them a Pearson's correlation (r) (Eq. 1) was performed after checking r assumptions [19] (Eq 1). All calculations were done using Rstudio [20] base statistical package. Figures were plotted using the packages ggplot2 [21], tidyr [25], and dplyr [25].

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (\text{Eq. 1})$$

where r is the correlation coefficient, x_i are values of de x variable, \bar{x} is the mean of the values of the x variable, y_i are values of de y variable, and \bar{y} is the mean of the values of the y variable.

RESULTS AND DISCUSSION

Applying the methodology described in the previous item for the study area, which represents monthly percentiles of 90% Tmax anomalies and persistence were obtained. Figure 2 illustrates the monthly distribution of Tmax anomalies in regions 1 and 2 (Fig. 2a and b, respectively) and the corresponding P90. Values above the threshold (blue dots) were considered extreme.

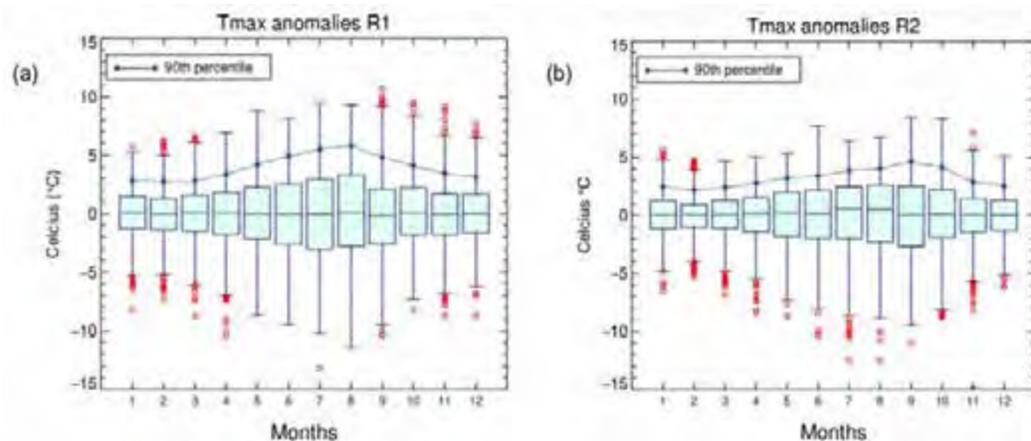


Figure 2. Box plots of the monthly distribution of Tmax anomalies for regions 1 (a) and 2 (b). The blue dots represent the monthly P90 threshold.

Figure 2 showed that the P90 threshold is higher in June, July, and August for R1, 4.9, 5.5, and

5.8 °C and, August, October, and September (4.04, 4.14, and 4.59 °C) for R2. Other authors also reported similar thresholds using other databases. For example, using long-term variations (1913- 2006) period of monthly average TMAX and TMIN records for southern Brazil [23] reported significant trends. Also, [24] observed that from the early 1980s until the early 90s a high-pitched and unparalleled warming in TMAX and TMIN time series. [25] found that heatwaves in southern Brazil typically occurred in spring and/or summer.

In Figure 3, the box plot containing the number of consecutive days in each month in which the Tmax anomalies remained above the threshold can be seen. Thus, the extreme temperatures selected in the analysis of Figure 2 were considered persistent enough to configure a HW event. In mean, higher persistence was observed in May, June, and July for R1 (~5 days) (Fig. 3a) and in February, April, and July for R2 (~ 6 days) (Fig. 3b).

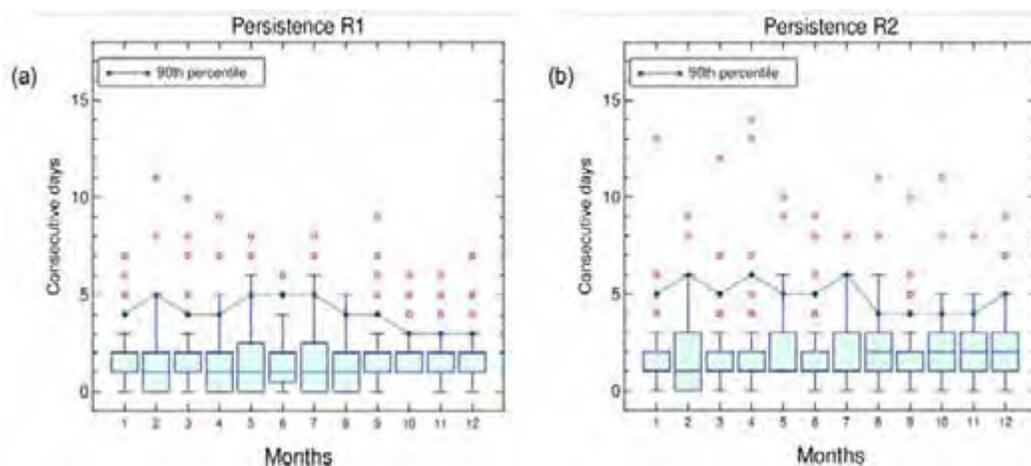


Figure 3: Box plot of the monthly number of consecutive days with Tmax above its threshold in regions 1 (a) and 2 (b). The blue dots represent the monthly P90 threshold.

Fig.4 shows yearly detrended soy and maize yield data (Fig. 4a) and persistence (days) and frequency (number of occurrences per year) (Fig. 4b). Higher persistence was observed in 2001, 2002, and 2014 with 9.3 days in mean; also, the frequency for those years was around 3 – 5 events for R1. For R2 higher persistence was encountered in 2014, 1987, 2007, and 1984 with 6.9 days average, frequencies were low with 3 – 4 days. For the SM yield (Fig. 4a), maize has suffered a linear trend since 1990, from 2000 kg ha⁻¹ to around 8000 kg ha⁻¹ in 2019. For soy, values were kept from under 2000 kg ha⁻¹ to ~3000 kg ha⁻¹ in 2019, having a normal nonlinear growth.

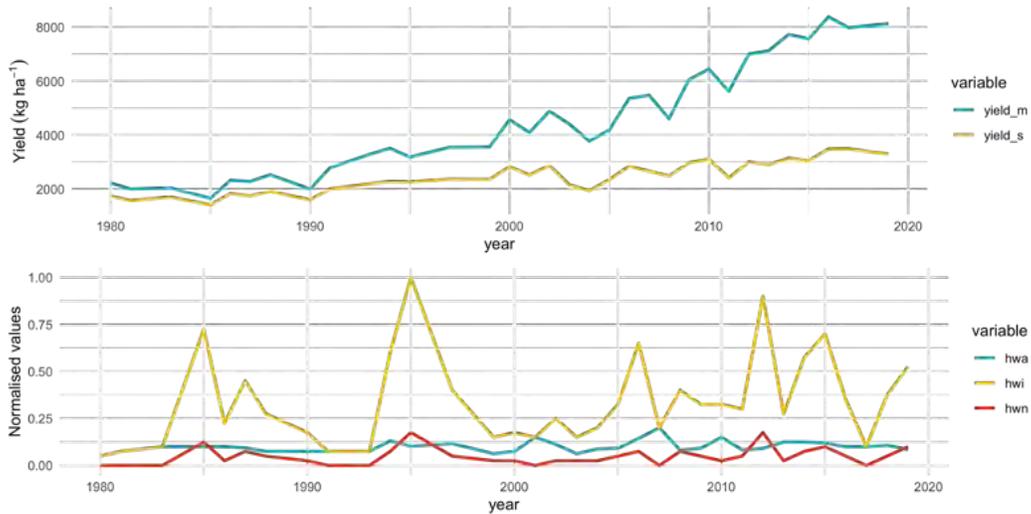


Figure 4. Yearly soy and maize crop yield and normalized heatwaves indices times series calculated based on CPC dataset for the Brazilian Subtropical Region.

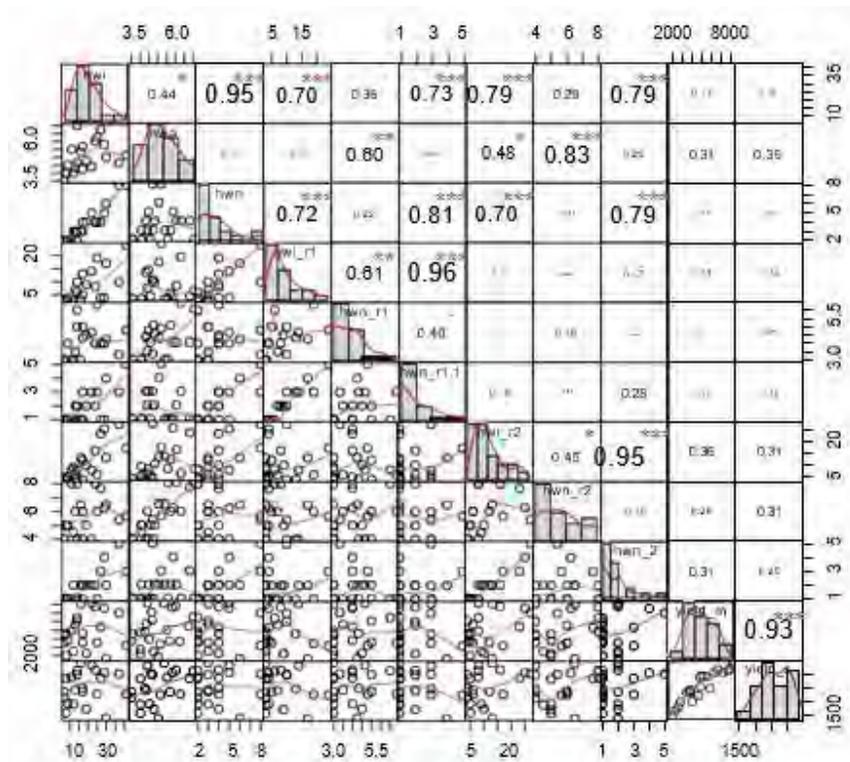


Figure 5. Correlation matrix between heat wave indices and soy and maize detrended yield for the Brazilian subtropical region.

After analysis of r assumptions, a correlation matrix was plotted (Fig. 5), between detrended maize and soy yield (lower panels) and average HW intensity (hwi), average (hwa), and number (hwn). Results showed the highest r for maize and soy with hwa with 0.31 and 0.39. Between regions, hwi and hwn r were higher in region 2 for maize (0.36, 0.31), and soy (0.31, 0.31). On average for region 1 correlations results were weak. Even when [26] detailed that the impact of comparable droughts or heat waves over the past four decades in UK since 1970, for many commodities, had a negligible effect on production, indicating that the sector is relatively well adapted to the current climate, here can be inferred that Brazilian agriculture is well adapted to HW since R1 R2 are constantly being hit by them.

Several new analysis such as detail agricultural indexes [27] and extreme indices [28], [29] should be addressed in conjunction with new statistical analysis in these regions to understand yield variability as a function of climate extremes.

CONCLUSIONS

P90 threshold is higher in June, July, and August for R1, 4.9, 5.5, and 5.8 °C and, August, October, and September (4.04, 4.14, and 4.59 °C) for R2. The extreme temperatures selected in the analysis were considered persistent enough to configure a HW event. In mean, higher persistence was observed in May, June, and July for R1 (~5 days) and in February, April, and July for R2 (~6 days). Maize has suffered a linear trend since 1990, from 2000 kg ha⁻¹ to around 8000 kg ha⁻¹ in 2019. For soy, values were kept from under 2000 kg ha⁻¹ to ~3000 kg ha⁻¹ in 2019, having a normal nonlinear growth. Results showed the highest r for maize and soy with hwa with 0.31 and 0.39. Between regions, hwi and hwn r were higher in region 2 for maize (0.36, 0.31), and soy (0.31, 0.31).

ACKNOWLEDGMENTS

The authors acknowledge the National Council for Scientific and Technological Development (CNPq, Brazil), the Coordination for the Improvement of Higher Education Personnel (CAPES, Brazil), also Diego Portalanza recognizes the Organization of American States (OAS) and the Coimbra Group of Brazilian Universities (GCUB), with the support of the Division of Educational Topics of the Ministry of Foreign Affairs of Brazil (MRE), through the OAS Partnerships Program for Education and Training (PAEC OAS-GCUB) for the Doctoral academic scholarship.

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POST-DEMOLITION AUTOCLAVED AERATED CONCRETE: RECYCLING OPTIONS AND VOLUME PREDICTION IN EUROPE

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ABSTRACT

Autoclaved aerated concrete (AAC) is an increasingly used building material due to its exceptional thermal properties. Post-demolition AAC is mainly disposed in landfills because of lacking established recycling processes. However, the growing demand for sustainable products, greenhouse gas reduction, decreasing landfill capacities and new legal frameworks require recycling options for post-demolition AAC.

Current research includes using post-demolition AAC recycling in the production of lightweight aggregate concrete, lightweight mortar, no-fines concrete, and floor screed. Even closed-loop recycling could be achieved by adding finely ground post-demolition AAC in the AAC production process or by producing belite cement clinker from post-demolition AAC as a substitution for Portland cement.

Predicting the generation of post-demolition AAC volumes is crucial for a recycling and circular management of AAC. But, post-demolition AAC volumes in Europe are currently neither recorded in statistics nor investigated in comprehensive studies. Therefore, a post-demolition AAC prediction model is presented that quantifies post-demolition AAC on a national and European level. Results show low volumes in South East, Western, and Southern Europe as well as Scandinavia due to small market sizes. In North West and Central Europe, especially the UK (700,000 m³) and Germany (1,200,000 m³) in 2020 drive post-demolition AAC volumes. The most significant post-demolition AAC volumes occur in Eastern Europe, especially in Poland (1,800,000 m³) and Russia (3,900,000 m³) in 2020. While relative volumes between the regions stay similar, the absolute post-demolition AAC volumes in Europe will nearly double in the next decade from 12.3 to 22.0 million m³.

KEYWORDS

autoclaved aerated concrete; circular economy; material outflow analysis;
post-demolition autoclaved aerated concrete; recycling

INTRODUCTION

Worldwide, resource consumption and CO₂ emissions are beyond a sustainable limit. Therefore, the UN aims at sustainable development goals like responsible consumption and production, climate action and sustainable cities [1]. Circular Economy plays an essential role to reach those goals – especially in the construction and demolition (C&D) sector, where substantial mass flows lead to high CO₂ emissions, energy and resource consumption and significant construction and demolition waste (C&DW) amounts. Worldwide, more than 3 billion tons of C&DW were generated in 2012 [2]. However, a considerable share of the potential of a circular economy remains unused [3].

Autoclaved aerated concrete (AAC) is produced from quartz sand, cement, quicklime, anhydrite, aluminium powder/paste (as aerating agent), and water. AAC has a porous structure, low density, and exceptional thermal insulation properties among mineral building materials. Therefore, AAC is popular for masonry units and mineral insulation boards, especially in residential buildings. And, construction and deconstruction processes of AAC require less effort than layered insulated materials (e.g. bricks with insulation) because AAC is a mono-material. This leads to time and cost savings in (de)construction processes and contributes to the high popularity of AAC. E.g. in Germany, the production of AAC began in 1950 [4], and in 2018, 23% (trending upwards) of the completed residential buildings were built using AAC [5].

AAC production waste or breakage is already recirculated. However, post-demolition AAC is not yet recycled because the porous structure, adhering substances, and small quantities of sulphate hamper high-quality recycling. Therefore, post-demolition AAC is mainly landfilled. However, decreasing landfill capacities and legal requirements – especially the European Waste Framework Directive 2008/98/EC – demand for AAC recycling. But, information on post-demolition AAC volumes is crucial to design and manage a circular supply chain for AAC. This study tries to fill the gap because only negligible information about recyclable AAC volumes in Europe is available as official statistics and comprehensive studies are lacking. First, a short overview of post-demolition AAC recycling options is provided. Then, expected post-demolition AAC volumes in Europe are quantified based on historic AAC production data, and building lifetime assumptions. Since comprehensive AAC production data is only available for Germany and the UK, post-demolition AAC volumes in other European countries and regions are predicted based on the current AAC market volume.

POST-DEMOLITION AAC RECYCLING OPTIONS IN LITERATURE

Reusing post-demolition AAC blocks is no practical possibility due to the need for an overly careful deconstruction process [6] and complex transportation and storage. However, crushed post-demolition AAC in fine powder or granulate form could be used in different recycling options. First, post-demolition AAC powder could be used in AAC production [7, 8] to establish a closed-loop recycling. However, only up to 20% of primary raw materials [7] or up to 50% of the sand [8] can be substituted by post-demolition AAC powder. Besides, belite cement clinker production from post-demolition AAC powder [9, 10] could handle significant amounts of post-demolition AAC, because it can be used as primary raw material in many applications such as AAC production (closed-loop recycling) or autoclaved sand-lime brick production (open-loop recycling).

Furthermore, various open-loop recycling options for post-demolition AAC are subject to current research. These options include the application of post-demolition AAC in light mortar [11], lightweight aggregate concrete [6, 11], floor screed [12], and no-fines concrete in the form of stumped concrete with decorative function or shuttering blocks [6]. Besides, there are suggestions for downcycling/utilisation options for post-demolition AAC like the use in phosphorus filters [13], fertilisers [14, 15] and landscaping [16].

Overall, promising recycling options for post-demolition AAC are presented in the literature. However, implementing a recycling network for these recycling options needs further knowledge on current and future post-demolition AAC volumes that can be expected.

POST-DEMOLITION AAC VOLUME PREDICTION IN EUROPE

Methodology

The European Waste Catalogue specifies different codes to record different types of waste. However, there is no AAC-specific code. In practice, post-demolition AAC is allocated to the codes 170101 (concrete), 170107 (mixtures of concrete, bricks, tiles, and ceramics) and 170802 (gypsum-based construction materials). Thus, no inferences about the post-demolition AAC volume are possible due to large volumes of different types of building rubble recorded in these codes. And, the literature on this topic is limited to stockpile studies, e.g. [17] and [18] for Germany, while comprehensive waste volume studies are missing. Therefore, [19] developed a model that predicts regional (NUTS 3 level) post-demolition AAC volumes in Germany based on AAC production, building lifetime assumptions, regional construction activity, and regional AAC popularity. This study uses the same methodology to determine current and future post-demolition AAC volumes in Europe, excluding regionality below the national level. Therefore, data on regional construction activity and regional AAC popularity are unnecessary. Building lifetime assumptions (for residential and non-residential buildings) are adopted from [19]. Residential and non-residential buildings are considered independently as they have different lifetimes. A triangular lifetime probability function with 35 and 95 years as lifetime boundaries and 65 years as the most probable lifetime is assumed for residential buildings. For non-residential buildings, a similar triangular lifetime probability function with lifetime boundaries of 15 and 100 years and a most probable lifetime of 40 years is assumed. The total post-demolition AAC volume from both building types is added up employing average shares of AAC used in residential and non-residential buildings. The share of AAC used in residential buildings is assumed to be 85.5% and 14.5% in non-residential buildings respectively following [19]. Overall, the post-demolition AAC volume in a country for a specific year is calculated based on these lifetime assumptions and national historic AAC production using the following equation:

$$pd\ AAC_{c,y} = \sum_{a=1}^{100} (AAC\ production_{c,y-a} * P_r(a) * 0.855 + AAC\ production_{c,y-a} * P_{nr}(a) * 0.145) \quad (Eq. 1)$$

pd AAC_{c,y} post-demolition (pd) AAC volume in country c and year y [m³]

AAC production_{c,y} AAC production volume in country c and year y [m³]

P_r(a) probability of a residential building's (r) lifetime of a years [-]

P_{nr}(a) probability of a non-residential building's (nr) lifetime of a years [-]

However, data availability differs between the European countries (Figure 1). Thus, there are three different post-demolition AAC prediction approaches based on data availability for every country (Figure 2).



Figure 1. Data availability for post-demolition AAC prediction in the European countries

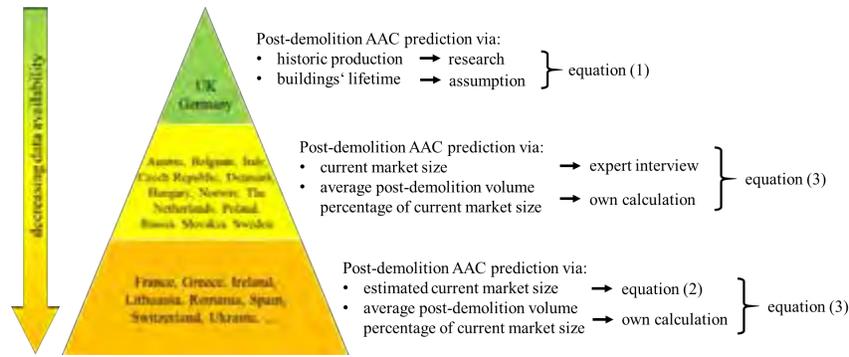


Figure 2. Different post-demolition AAC prediction approaches depending on national data availability

Comprehensive national AAC production data is only available for Germany [19] and the United Kingdom (direct inquiry to the UK Department for Business, Energy & Industrial Strategy). Therefore, for the other European countries another approach is developed: First, current AAC market sizes which reflect current production volumes are researched. Data is available for Austria, Belgium, Czech Republic, Denmark, Hungary, Italy, Norway, The Netherlands, Poland, Russia, Slovakia, and Sweden (expert interview: Dr. Oliver Kreft, Xella Technologie- und Forschungsgesellschaft mbH). Second, Europe is divided into different regions, and a representative country for every region is selected (Figure 3) to fill the data gap of the missing countries (countries with no data in Figure 1). All countries with missing market size data in a region are assumed to have the same AAC market size per population size as their representative country. So, the absolute market size is calculated via population data [20] using equation (2). This calculation allows an extension of the AAC market size estimation to whole Europe.



Figure 3. European regions and their representative countries used for post-demolition AAC prediction

$$AAC\ market_c = AAC\ market_{rep} * \frac{population_c}{population_{rep}} \quad (Eq. 2)$$

| | |
|---------------------------|---|
| AAC market _c | current AAC market size in country [m ³] |
| AAC market _{rep} | current AAC market size in representative country [m ³] |
| population _c | population in country [-] |
| population _{rep} | population in representative country [-] |

Third, post-demolition AAC volumes have to be calculated for the countries where only current market size data or estimation is available. To do so, the average post-demolition AAC percentages of current production volumes in Germany and the UK are taken which show a similar increase in the following years. Therefore, it is assumed that the post-demolition AAC volume for every country equals a particular percentage of the current market size, depending on the year. Finally, post-demolition AAC volumes for every European country is calculated using the following equation:

$$pd\ AAC_{c,y} = AAC\ market_c * percentage_y \tag{Eq. 3}$$

$pd\ AAC_{c,y}$ post-demolition (pd) AAC volume in country and year [m³]
 $AAC\ market_c$ current AAC market size in country [m³]
 $percentage_y$ post-demolition AAC percentage of the current market size in year [-]

Results

Post-demolition AAC volumes can be calculated for Germany and the UK using equation (1) because historical production data is available. In contrast to the German dataset (Figure 4 (a)), UK production data only goes back to 1967. Therefore, a linear increase for the period 1950 to 1966 is assumed (Figure 4 (b)). In our model, we calculated that significant post-demolition AAC volumes have occurred since the year 2000 in both countries (Figure 4). In the following years, calculated post-demolition AAC volumes increase sharply and constantly in both countries, exceeding 1 million m³ annually in 2018 (Germany) and in 2026 (UK) and reaching more than 4 million m³ in Germany and more than 2 million m³ in the UK in 2050. This rise would reach/exceed the AAC production in the UK/Germany if production volumes stay on today's level.

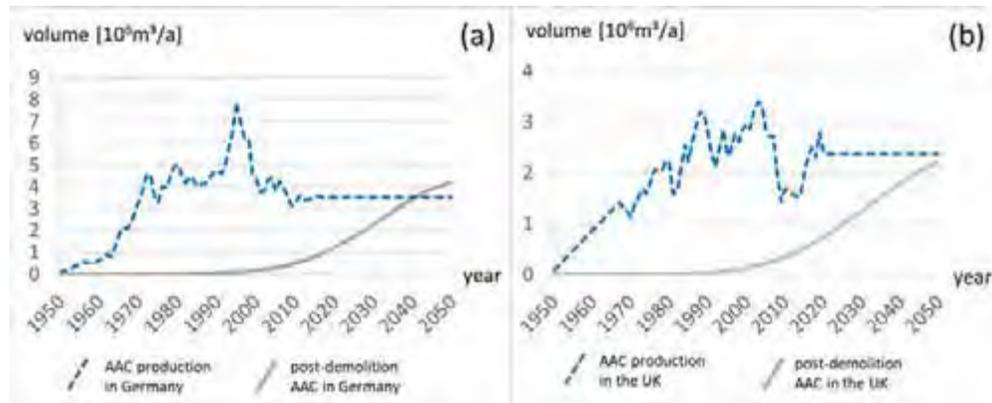


Figure 4. AAC production (dashed blue line) and post-demolition AAC (grey line) in Germany (a) and the UK (b)

The calculation of post-demolition AAC volumes for all other countries is based on current market sizes or market size estimations and the average post-demolition volume percentage of the current market size. The average percentage is determined for different years using the German and UK calculations calculated e.g. for 2020, 2025, and 2030 (Table I), where the German and the UK percentages are relatively close to each other. In the more distant future, they diverge more. The post-demolition AAC calculation (Table II, Figure 5) for 2020 shows relatively low volumes in South East Europe and Scandinavia, which can be explained by their small market sizes. Somewhat larger volumes can be found in the region Western and Southern Europe due to higher population and in North West Europe, where the UK alone accounts for 700,000 m³. In Central Europe, volumes are double the amount of North West Europe with the highest volume in Germany (1,200,000 m³). The most significant post-demolition volumes occur in Central-Eastern and Eastern Europe due to large markets in Poland and Russia. These two countries together (Poland: 1,800,000 m³, Russia: 3,900,000 m³) account for nearly half of the total European post-demolition AAC volume of around 12,290,000 m³ in 2020. A sharp increase of post-demolition AAC volumes throughout Europe is noticeable in the next decade. Absolute numbers nearly double in Europe from around 12.3 to 22.0 million m³ in only ten years. Increasing AAC production in the 60s, which is expected to reach its end of life around 2030, can explain this rise. However, the relative volumes between the regions stay similar in 2025 and 2030.

Table I: Post-demolition AAC volume percentage of the current market size

| year | percentage Germany | percentage UK | average percentage |
|------|--------------------|---------------|--------------------|
| 2020 | 35.2% | 31.9% | 33.5% |
| 2025 | 49.2% | 42.9% | 46.0% |
| 2030 | 65.2% | 54.6% | 59.9% |

Table II: AAC market sizes and calculated post-demolition AAC volumes for 2020, 2025, and 2030 of all European countries (excluding small countries with less than 100,000 inhabitants)

| country | (estimated*) market size [m ³] | post-demolition AAC 2020 [m ³] | post-demolition AAC 2025 [m ³] | post-demolition AAC 2030 [m ³] |
|------------------------|---|---|---|---|
| Albania | 79,885* | 26,795 | 36,763 | 47,871 |
| Austria | 122,000 | 40,921 | 56,144 | 73,108 |
| Belarus | 751,782* | 252,158 | 345,969 | 450,502 |
| Belgium | 330,000 | 110,687 | 151,866 | 197,751 |
| Bosnia and Herzegovina | 92,105* | 30,893 | 42,387 | 55,193 |
| Bulgaria | 195,405* | 65,541 | 89,925 | 117,095 |
| Croatia | 115,159* | 38,626 | 52,996 | 69,008 |
| Cyprus | 12,651* | 4,243 | 5,822 | 7,581 |
| Czech Republic | 1,160,000 | 389,080 | 533,831 | 695,124 |
| Denmark | 325,000 | 109,010 | 149,565 | 194,755 |
| Estonia | 105,216* | 35,291 | 48,420 | 63,050 |
| Finland | 312,061* | 104,670 | 143,610 | 187,001 |
| France | 696,788* | 233,712 | 320,661 | 417,547 |
| Germany | 3,477,279 | 1,223,853 | 1,709,977 | 2,267,974 |
| Greece | 112,809* | 37,838 | 51,915 | 67,601 |
| Hungary | 269,000 | 90,226 | 123,794 | 161,197 |
| Iceland | 11,500* | 3,857 | 5,292 | 6,891 |
| Ireland | 164,442* | 55,156 | 75,676 | 98,541 |
| Italy | 650,000 | 218,019 | 299,129 | 389,509 |
| Latvia | 153,331* | 51,429 | 70,563 | 91,883 |
| Lithuania | 222,759* | 74,717 | 102,514 | 133,487 |
| Luxembourg | 25,267* | 8,475 | 11,628 | 15,141 |
| Malta | 4,707* | 1,579 | 2,166 | 2,820 |
| Moldova | 322,249* | 108,087 | 148,299 | 193,106 |
| Montenegro | 17,401* | 5,837 | 8,008 | 10,428 |
| Netherlands | 410,000 | 137,520 | 188,682 | 245,690 |
| North Macedonia | 57,718* | 19,359 | 26,562 | 34,587 |
| Norway | 17,000 | 5,702 | 7,823 | 10,187 |
| Poland | 5,400,000 | 1,811,235 | 2,485,074 | 3,235,923 |
| Portugal | 109,958* | 36,881 | 50,602 | 65,892 |
| Romania | 1,551,282* | 520,322 | 713,898 | 929,598 |
| Russia | 11,590,000 | 3,887,448 | 5,333,705 | 6,945,249 |
| Serbia | 243,923* | 81,815 | 112,253 | 146,170 |
| Slovakia | 650,000 | 218,019 | 299,129 | 389,509 |
| Slovenia | 57,580* | 19,313 | 26,498 | 34,504 |
| Spain | 500,609* | 167,911 | 230,380 | 299,988 |
| Sweden | 106,000 | 35,554 | 48,781 | 63,520 |
| Switzerland | 356,663* | 119,630 | 164,136 | 213,729 |
| Ukraine | 3,518,816* | 1,180,260 | 1,619,355 | 2,108,633 |
| United Kingdom | 2,291,135 | 730,576 | 982,073 | 1,251,563 |

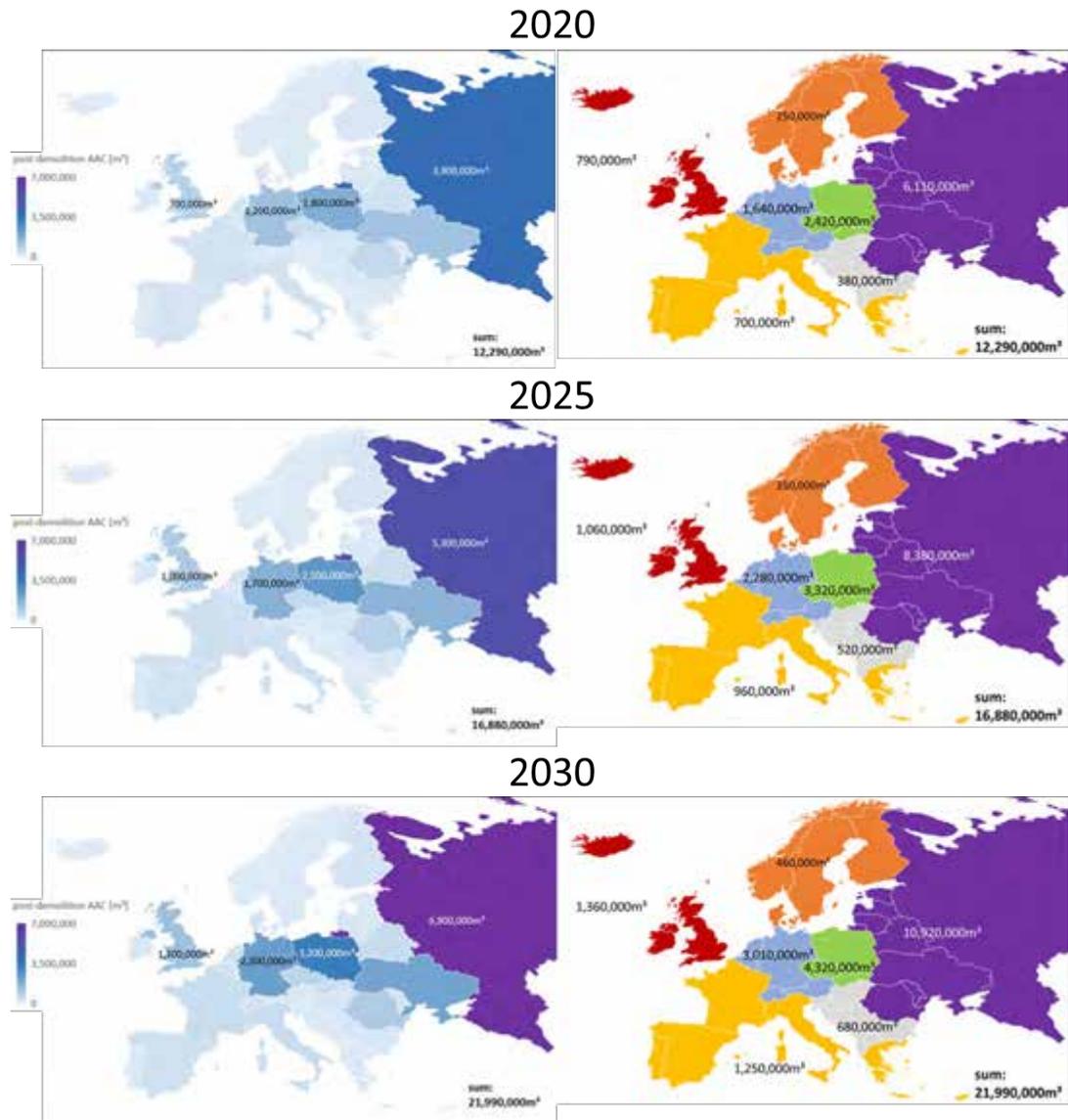


Figure 5. Post-demolition AAC volumes in Europe for 2020, 2025 and 2030

The average post-demolition volume percentage of the current market size has a great influence on the total European post-demolition AAC volume because it is used in the prediction for every country except for Germany and the UK. Therefore, a sensitivity analysis of European post-demolition AAC volumes with regard to this percentage is carried out (Table III). The analysis shows that a +/-10 %-point variation changes the total European post-demolition AAC volume by around 3 million m³. Thus, the post-demolition AAC volume could reach more than 15 million m³ in 2020 and even more than 25 million m³ in 2030.

Table III: Sensitivity analysis of European post-demolition (pd) AAC volume with regard to the post-demolition percentage of the current market size

| year | percentage (baseline) | pd AAC volume [m³] | percentage (10 %-points) | pd AAC volume [m³] | percentage (+10 %-points) | pd AAC volume [m³] |
|------|-----------------------|--------------------|--------------------------|--------------------|---------------------------|--------------------|
| 2020 | 33.5% | 12,290,000 | 23.5% | 9,200,000 | 43.5% | 15,360,000 |
| 2025 | 46.0% | 16,880,000 | 36.0% | 13,790,000 | 56.0% | 19,950,000 |
| 2030 | 59.9% | 21,990,000 | 49.9% | 18,900,000 | 69.9% | 25,070,000 |

Limitations and Shortcomings

An essential component of the post-demolition AAC prediction is the assumption of lifetime functions for residential and non-residential buildings. However, the lifetime functions are based exclusively on literature values. Empirical data is not available. And, various building characteristics (e.g. monument conservation, building material, construction technique, floor plan, renovation) influence its lifetime fundamentally. Overall, the lifetime functions are subject to noticeable uncertainties.

Furthermore, comprehensive production data is scarce, so only post-demolition AAC volumes in Germany and the UK can be calculated using the basic approach. For all other countries, post-demolition AAC volume is calculated using the current market size's average post-demolition volume percentage. This percentage is calculated as the mean value of only two countries (Germany and the UK) and thus also associated with uncertainties. Besides, reliable data on the current market size is only available for some countries. The market size of the remaining countries has to be estimated. Generally, an AAC-specific waste code or AAC waste statistics are missing but could help to quantify the available post-demolition AAC volume for recycling. Furthermore, the used percentage represents the situation in the longer existing AAC markets of Germany and the UK while AAC markets especially in Southern and South East Europe may be much younger and used percentages are not suitable. A change would shift post-demolition AAC volumes into the future. In general, including comprehensive AAC production or market size data of the past would improve the prediction of the model.

CONCLUSION

A European prediction model was developed to assess future post-demolition AAC volumes at national level. In 2020, volumes are the largest in Russia (3,900,000 m³) and Poland (1,800,000 m³). In other regions, Germany (1,200,000 m³) and the UK (700,000 m³) account for the largest expected national post-demolition AAC volumes. Furthermore, post-demolition AAC volumes in Europe will increase considerably in the following decade from 12.3 to 22.0 million m³. Therefore, AAC recycling has to be fostered to avoid landfilling these volumes and eventually to substitute primary construction material.

Further research could focus on gathering data on AAC production and AAC market sizes for more European countries to improve the prediction quality. Furthermore, building lifetimes should be further investigated. Especially knowledge on the lifetimes of different AAC products would be interesting. The presented model can be transferred to other regions/continents and to other building materials like clay bricks, timber, sand-lime bricks, or lightweight concrete blocks. To do so, adaptations on production data and possibly building lifetimes are necessary.

ACKNOWLEDGEMENT

This work was supported by the Federal Ministry of Education and Research (BMBF) Germany within the research project REPOST [grant number: 033R249B]. We gratefully thank Xella Technologie- und Forschungsgesellschaft mbH (Dr. Oliver Kreft), and the United Kingdom Department for Business, Energy & Industrial Strategy (Oliver Wright) for the constructive support and for providing valuable data. The responsibility for the content of this publication lies with the authors.

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TRADITIONAL WATER SYSTEMS: LEARNING FROM LONG-LASTING INDIGENOUS CULTURES

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ABSTRACT

Research on “Traditional Water Systems” offers insights on comprehensive, diverse and circular water management models. Since ancient times, humankind has been modelling territories and transforming natural bodies of water to obtain controlled hydraulic systems. This resourcefulness made it possible to settle and cultivate all kinds of topographies according to water availability, consolidated knowledge, and climate conditions. These transformations asked for precise reading of the landscape and the necessity to balance water and land, permeable and impermeable surfaces. Therefore, as strongly expressed by Shannon, “the primitive logic of cut-and-fill and differences in micro- topography was a powerful tool. Levels of inundation determined distinct land uses, and therefore the definition of wet/dry, productive/inhabited, and safe/unsafe parts of the land mosaic was considered essential” [10].

As a reaction to changes (population growth, land use, and climate variations, etc.), innovative measures to retain, infiltrate, drain, flood, and reuse water were taken by those living and knowing the territory. These Traditional Water Systems have been crucial in developing thriving and prosperous societies. Some of the water systems are still in use, indicating the inevitable involvement and care of people. For today, these systems offer vivid insights for more communal, people-oriented, resilient, ecologically rich and multifunctional approaches towards the landscape.

By using the illustrative method, Traditional Water Systems reveal their secrets. Researching on and learning from them deliver lessons for redesigning contemporary technical-driven water management systems into circular landscapes.

KEYWORDS

Landscape Architecture, Traditional Water Systems, Comprehensive Water Design, Water Stories

INTRODUCTION

The research on Traditional Water System (TWS) is carried out within the Circular Water Stories (CWS) design laboratory, as part of the graduate ‘*Flowscapes*’ studio^a of the Landscape Architecture master track at the Faculty of Architecture and the Built Environment (TU Delft, the Netherlands). In the CWS lab, under the guidance of Associate Professor Inge Bobbink, graduate students research Traditional Water Systems by applying the illustrative method, which offers insights into the management of indigenous water systems all over the world. By mapping TWS of their own choice, students gather knowledge for their graduation thesis that is directly (as sites of intervention) or indirectly (as insights on designing with water) linked to the lab’s landscape research.

Throughout the world, people have transformed natural water flows into ingenious and controlled water systems, settling down in unfavourable environments thanks to outstanding technical skills. TWS can be read as comprehensive systems closely connected to the existing landscape and the people inhabiting it, creating new cultivated landscapes. The transformation asked for precise reading of the landscape while looking for a new balance between water and land, permeable and impermeable surfaces. TWS developed over a long period by trial-and-error and, because of this, store knowledge, especially on adaptation to an ever-changing context. As a reaction to all kinds of changes (population growth, usage, climate, tools and means, etc.), measures to retain, infiltrate, drain, flood and reuse water were developed by the people living and knowing the area. Many of these systems are still alive and actively used, testifying to the inevitable involvement of the people living in the surrounding areas. Therefore, the research on TWS aims to deliver lessons for redesigning today’s often-anonymous, technical-driven water management systems into more communal, resilient, ecological and multi-functional public spaces^b.

The illustrative method, initially developed by I. Bobbink and M. Ryu in 2017, is used as a starting point to analyse the rationality of TWS, their management, spatial appearance, consistency and coherence as part of a bigger, territorial landscape, and how people constructed and used them over time. During the research in the first edition of the Circular Water Stories lab (a. y. 2018-19), a fixed content table and drawing legend are developed for all the projects, to build a strong comparative framework. The most important set of drawings is the one in which the water system is projected onto a topographical map to understand the water system’s functionality. Next to it, students experiment on representing the system’s circularity. Within the second edition of the lab (a. y. 2019-20), a glossary, categorized by “water landscape elements”, “water works” and “water stories”, is added. These categories derive from the methodological application itself: while analysing and sequentially comparing the cases, common elements, structures and activities have arisen. “Water landscape elements” indicate those components of a large-scale water system made with materials like soil, stones etc. reshaping directly the water flow: they are created by people using mainly natural materials and differ according to the territory. “Water works” are built structures, like sluices, weirs, pumping stations of different materials involving a certain amount of craftsmanship: they are created by people using mainly artificial materials. Most of these innovations developed at the same time in different places and some of these water works were installed on different continents by knowledge transfer. “Water stories” are included in the research by translating the method of the “landscape biography”^c into a “visual water biography”, in collaboration with Suzanne Loen [4]. Water stories consider people’s involvement in water-related activities and illustrate actions (spiritual, agricultural, etc.) and the traditional tools employed. According to the examples considered until now, these stories refer to a certain kind of use linked to the water element (for example, wet ploughing in Kuttanad, India, cleaning mosques and husking rice in Kampung Naga, Indonesia, smoking fishes and eels in gum trees in Gunditjmara Country, Australia). By approaching these elements, it becomes easier to draw the circularity of the system. The third edition of the lab (a. y. 2020-21) contributes to consolidating the methodology applied during the previous two editions, adding five more water systems to the examples analysed.

The art of this educational research is to organize the outputs in the same graphical way – yet with a considerable amount of freedom in terms of graphic expression for each student. Black, greys of different opacities, white, light blue/green (for the water) and orange (for highlighting relevant parts of the drawing) compose the colour palette. By reducing the number of colours, students are required to carefully think about what is worth to be displayed and simplify the information illustrated. The sequence, the style and the findings of the drawings allowed the research group to compare the different TWS investigated.

Until now, the three laboratories of CWS have gathered a discrete quantity of information already able to delineate relevant categories and discoveries. A new cycle of CWS started in September 2021.

THE NECESSITY TO STUDY *TRADITIONAL WATER SYSTEMS*

TWS, resulting from the direct interaction of indigenous populations, local cultures, the necessity of survival and the territory they live in, retain a priceless tangible and intangible landscape heritage. Both working tools, water works, and other physical products of human creativity and practices, representations, expressions, knowledge, skills are recognized as part of the Cultural Heritage [11]. More than just *being* heritage, the study and understanding of TWS elements and traditions, that by nature have evolved and adapted over time, contribute and enrich those design interventions that build on existing structures, particularly at a time of climate change.

According to this, three important lessons can be learnt from Traditional Water Systems. First, “Design with Water”: the understanding of the landscape morphology, its formation and evolution, and the existing water system is pivotal to be able to relate and intervene. TWS can be read as comprehensive and integrated structures closely intertwined to the current ecosystem and as integral parts of the landscape, and because of this, they can be used as a design manual. Secondly, “Integration”: TWS have been developed over a long period by trial-and-error and store a lot of knowledge regarding the changes of the system. As a reaction to different climate periods, management measures to retain, infiltrate and reuse water have been added, which is why TWS very often combine these functions integrally. Thirdly, “Circularity”: especially in those geographical areas where water is already scarce, TWS have evolved most inventively to “recycle” the water within. This reuse led to the technological enrichment of the system itself and the survival of the populations that developed it. Because of this, the knowledge stored in TWS can inspire spatial, smart and sustainable approaches to water management [10].

To reveal the knowledge held by TWS, a comprehensive method has been studied and put together accordingly. The method’s goal is to read the systems through common guidelines, creating and enriching a comparative framework. This makes it possible to register and analyse different water systems characterized by different uses and located in the most diverse landscapes, regulated by different cultural contexts acting on different scales.

Complex systems, where water is used in different ways according to its specific location, have directed the interest of the research group. In fact, by focussing on comprehensive strategies, more can be learnt about the interaction among landscapes, ecosystems and uses, looking for a balance.

LANDSCAPE, WATER SYSTEMS AND WATER WORKS

Over thousands of years, human beings have transformed and expanded natural water systems into human-made water systems, since the possibility of settling has always depended on the availability of water. The transformation of natural water systems could only begin with the clear reading of the natural conditions, fluvial characteristics, topography and soil conditions of the landscape and, by trial-and-error, natural water flows were manipulated towards a variety of ends. Through the centuries, populations occupied the landscape by reading and understanding it and deriving from this knowledge the functional creation of water systems. Ingenious water networks were built for collecting and retaining water, draining and irrigating land while water works were already dug in the Iron Age providing a permanent water supply. Through these landscape transformations, the human-made water systems have repeatedly become the dominant structural element of cultivated and urbanised landscapes and part of cultural heritage. In cases such as polder landscapes or *sawas* (rice terraces), the water system determines completely the character of the landscape [4].

Based on this research, numerous types of water systems (e.g., irrigation systems, drainage systems or systems develop for water supply, etc.) have been built and developed. Many have disappeared for a variety of reasons (e.g. wars, natural or anthropogenic disasters, climate changes, modern industrial innovations, etc.) but many have evolved, adapting their structures according to the new living conditions of their habitats. This motivates the choice of deepening the research on TWS, their evolution and current state: these lasting water systems are worth studying since their survival testifies to their usefulness and integration within the surrounding landscape.

THE FIVE KEY ELEMENTS OF *TRADITIONAL WATER SYSTEMS*

To proceed with the analysis, understanding and comparison of TWS, five common key elements have been selected to organize and argue the research. Here below are presented those research questions that have guided the in-depth analysis of TWS.

1. Relation to the **Context** - geomorphology, hydrology, **Climate** and **Catchment area**. What is the role of the surrounding characteristics and how have they influenced TWS? How the landscape and atmospheric conditions have shaped the systems? How the systems themselves have influenced and modified the surrounding natural landscape?
2. **Transformation over time** - evolution. How people have interpreted external stresses and have modified the TWS accordingly? What kind of stresses and of what nature? How the system has answered these natural and/or anthropogenic stresses? Which elements (water works, etc.) have changed through time and which elements have been kept and conserved as they originally were?
3. **Human interactions** - stories and usages, socio-cultural system behind the creation and use of the TWS. What human actions, experiences, and activities characterize and shape TWS? How these have changed and evolved through time according to the system's change? Which uses do people make of these systems? What do they obtain (food, energy, clean water, defence, etc.)? What kind of consideration do they have in today's societies?
4. **Water System** and **Circularity**. How does the TWS technically work? What elements have been developed to increase its efficiency and productivity? How does the water flow in relation to the system structure (linearly, circularly, etc.)?
5. **Values** - Landscape Values, Strategic Values, Functional Values, Material and Tangible Values, Sustainability Values, Ethnographic and Identity Values (based on the PhD work of G. Rivero-Lamela). Which specific values can be derived from the comprehensive analysis of a TWS? Which general values can be derived from the comparison of TWS? Are there any recurrent values that determine the successfulness of certain systems with respect to others? What lessons can be learnt? How these values could be integrated into new design-with-water project proposals?

THE ILLUSTRATIVE METHOD

To answer the previous research questions, the illustrative method has been developed. By using the analytical drawing format, the focus lies on the spatial and visual aspects of the system. The method is developed particularly for TWS as they are strongly related to their geomorphological and socio-cultural context, two elements that, through their millennial intertwining and reciprocal influence, generate a "*landscape*".

Analytical drawings mainly focus on different aspects of water systems and deliver various inputs, which can identify water heritage aspects more comprehensively. To address the complexity of a TWS, multiple types of illustrations are combined, like photos, maps, diagrams and architectural drawings (plans, sections and 3D) scales and different levels of abstraction are investigated. Sometimes, various maps are needed to show transformations through time or find relations between water systems, soil information and height differences. The main illustration per case is preferably a map on the scale of the whole water system (i.e., catchment area), including its water works and revealing its functions. Photos at different scales are used to show the relation with the surrounding landscape, the water systems, water works and other elements such as plants, buildings and people using the system. The drawing styles of the illustrations can vary from hand drawings to computer drawings. After consulting the whole set of illustrations, the reader should be able to understand not only the water system and its water works but also the specifications of the system in relation to the use and the landscape.

The selected types of drawings are shortly described below. Eight types of drawings have been identified to represent successfully the essence of TWS. The illustrations are organised from large to small scale: from territorial landscapes through water systems to water works, from general overviews to specific details.

Context - Graphic introduction of the project considered through maps representing its location on a continental scale, national scale, and regional scale with a text description of relevant information (year or period of development, main function(s), area occupied, main components and water works, status, etc.). The regional-scale map is more detailed and includes topography and water system.



Figure 1. Context analysis: continental scale, national scale and regional scale (example: Fishing Valleys, Italy, A. Chouairi).

Climate - Diagram of climate zone combined with precipitation distribution over the year and additional relevant information (highest, mean, and lowest temperatures, annual millimetres of precipitation, humidity percentage, average wind speed, pressure rate, hottest, coldest, wettest and windiest months, annual rainfall per year, etc.). These diagrams are unified after students have handed in their diagrams to make it easier to compare the situations. For detecting the climate zones, the Köppen-Geiger-classification is used. Since many of the projects see their origin in a fairly ancient time, students have tried to collect climate information from those periods, a rather complex and not very detailed research, but which could bring to light climatic situations very different from those of today. In addition to this, nowadays the climate is changing more rapidly due to human actions and finally, this climate aspect will increasingly play a decisive role.

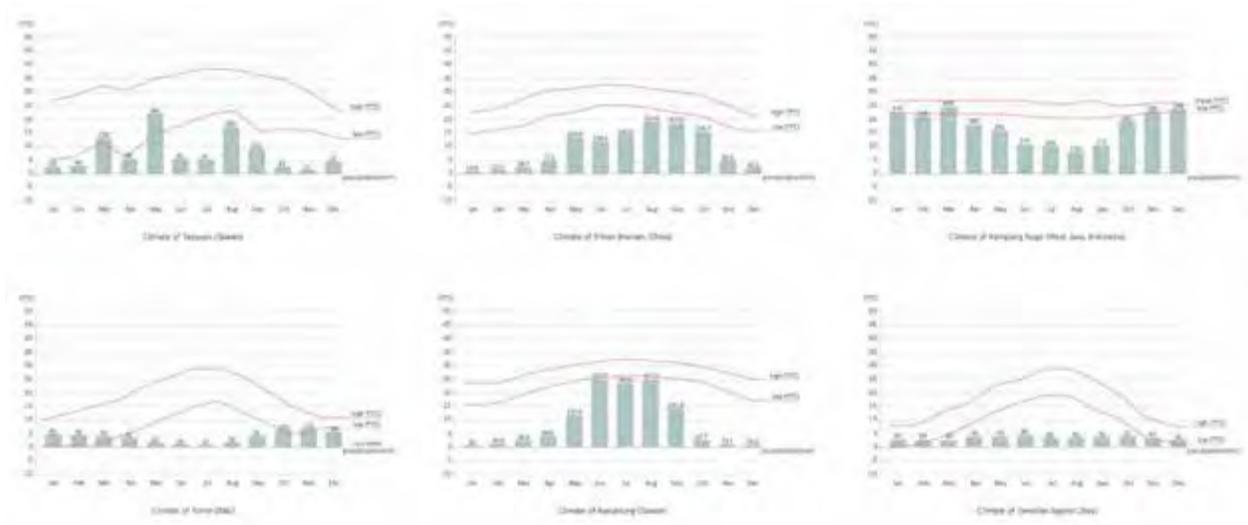


Figure 2. Climate analysis: average precipitation and highest and lowest temperatures of six cases (examples, from left to right, first line: Taoyuan – Taiwan, Hainan – China, West Java – Indonesia; second line: Rome – Italy, Kaoshiung – Taiwan, Venetian Lagoon – Italy). Image processed by: Y. T. Kao and R. Yan.



Figure 3. Köppen-Geiger climate classification maps at 1-km resolution. From light to dark grey: tropical, dry, temperate, continental and polar. The orange dots point out the twenty-two locations of TWS analysed in the CWS laboratories (2018-2021). Image processed by M. Pouderoijen.

Catchment area – Map of the water system (plan or perspective bird-eye view) on a regional scale, from inlet to outlet (lake, river, or ocean) with water works positioning, combined with the topographical map and notions of geomorphology, if relevant. Additional information on disappeared elements can be represented. Defining the catchment area is a complex task, for which the understanding of the area of influence of the system is fundamental [7]. For example, when considering a coastal zone, since the catchment area cannot be defined as such, the student needs to select a coherent area that defines the cultivated water system.

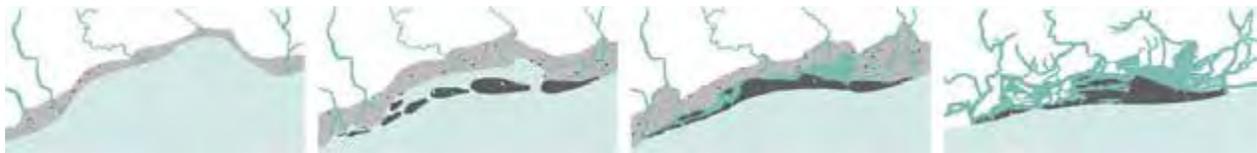


Figure 4. Catchment area: watershed defining the water system (examples, from left to right: Fishing Valleys – Italy, A. Chouairi; Xinghua Duotian Agrosystem – China, P. Surajaras; Aboriginal Aquaculture – Australia, M. José Zúñiga).

Transformation over time (origins and evolution) - Sequence of diagrams synthetically representing the system's development over an extended period and the different functions and uses according to seasons. Historical maps and diagrams show the different phases of the water system over time. They reveal the strong connection between the water systems and the evolution of the civilization around them: where a successful water system is found, there exists a flourishing civilisation. On the contrary, if water is lacking, civilisation declines. Historical photos are added, relevantly highlighting the interactions between man and landscape. Within this range of moments in history, we decide which period of the water system is the most interesting to be studied. Because many of these systems are in decline, for several reasons today's situation is not always the most interesting one.



The Roman Aqueducts. From left to right: from 312 B.C. to 226 A.D., V to XV century and XVI to XVII century.



Kuttanad Kayalnilam Agrosystem. From left to right: Pre-Holocene, Middle-Holocene, Late-Holocene and early XIX century.



Ksókong Tsùn Irrigation System. From left to right: before 1837, 1837-1838, 1842 and 1931.

Figure 5. Transformation through time (examples, from top to bottom: The Roman Aqueducts – Italy, C. Di Nicola; Kuttanad Kayalnilam Agrosystem – India, N. Ali; Ksókong Tsùn Irrigation System – Taiwan, M. Lin).

Human interactions – Photos highlighting the interaction between human beings, landscape, water system and water works. The pictures may represent workers and/or visitors, water landscape elements, water works, working tools, site-specific housing and transportation means, etc. The images are collected consulting historical sources, often explorations conducted by anthropologists or historians. Today's photographs are employed to show, where possible, the structure of the remaining elements and their relationship with the modern context.

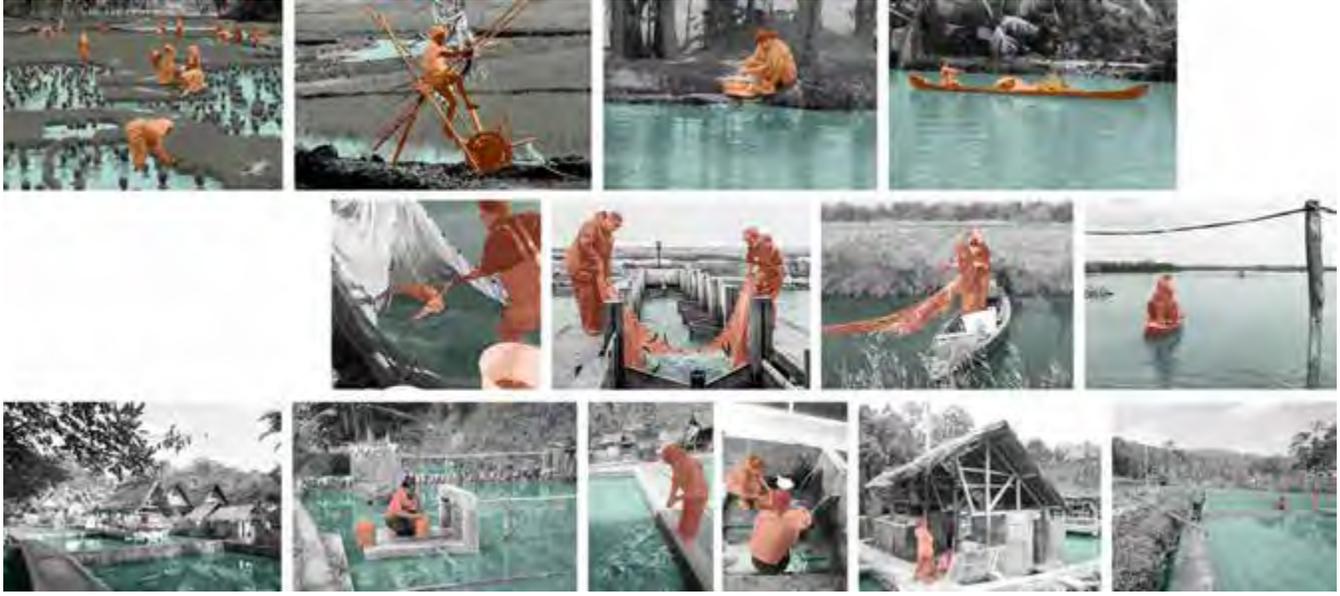


Figure 6. Human interactions (examples, first line: Kuttanad Kayalnilam Agrosystem – India, N. Ali; second line: Fishing Valleys – Italy, A. Chouairi; third line: Kampung Naga – Indonesia, A. Prestasia and B. Kim).

Water System – Map technically representing the water management of the system (plan or perspective bird-eye view), using as a base a height map, on a local level: its delimited extension, type of water (salt, brackish, or fresh), water landscape elements, flooded areas, underground waters, dry soil and marshes, fields, crops growing on land or water, relevant vegetation, buildings related to the considered water system, water works (embankments, dams, sluices, stepwells, canals, ditches, fishponds, traps, etc.), etc. The drawing, representing applicable landscape elements, determines the functional and spatial dimension of the system. By making the drawing, students figure out how the water system works.



Figure 7. Water System (examples, from left to right, first line: Fishing Valleys – Italy, A. Chouairi; Aboriginal Aquaculture – Australia, M. José Zúñiga; Xinghua Duotian Agrosystem – China, P. Surajaras).

Circularity – xonometric or perspective section explaining the circular interaction between water flows, system functioning, activities, people operating and ecology in relation to seasonality. The diagram represents significant aspects as sustainability and the spiritual or symbolic importance of the water system. The drawings are scaleless, connect the regional and the local scale and incorporate all those relevant elements that emerged from the research directly linked to the water system.

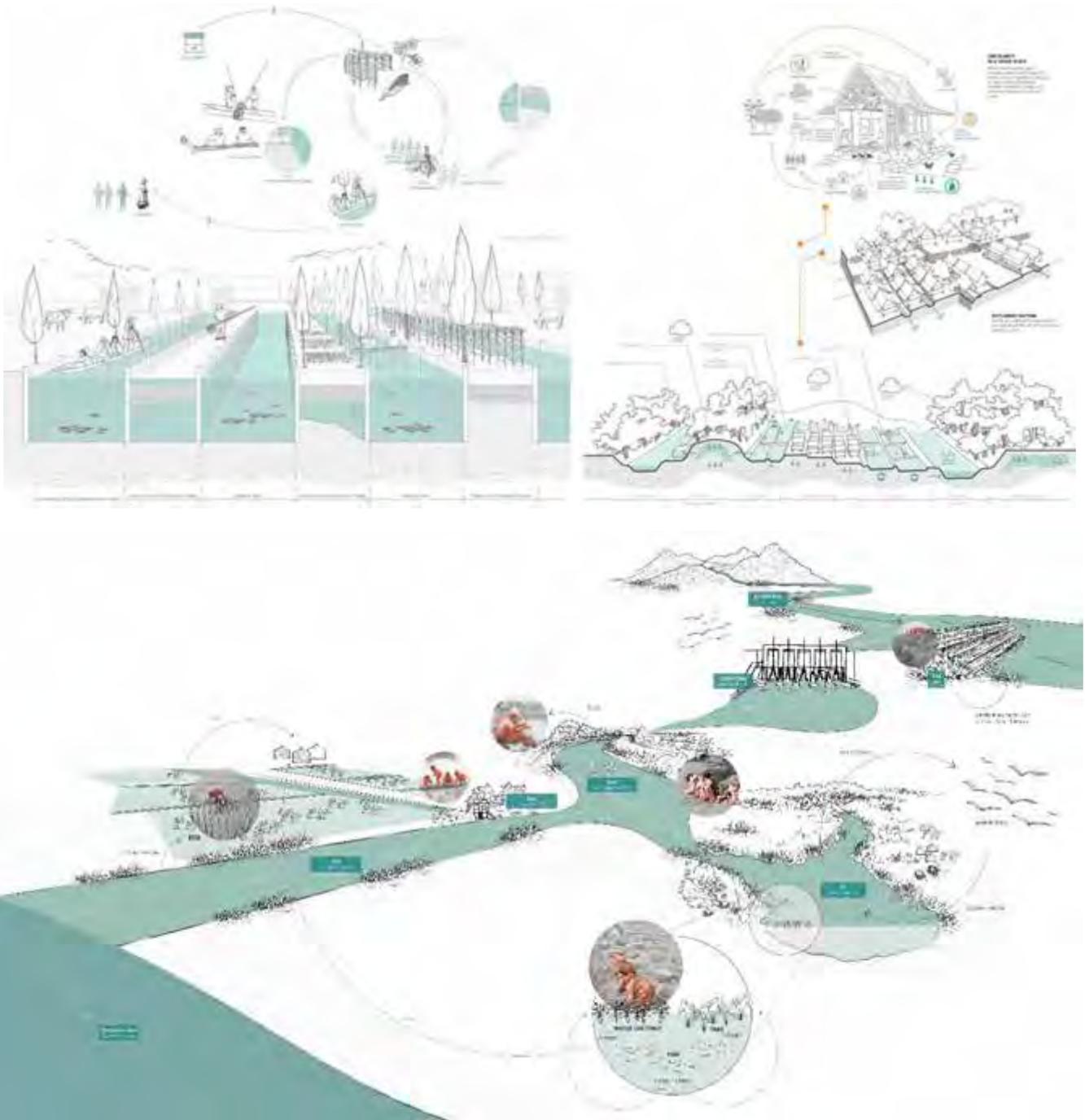


Figure 8. Circularity (examples, from left to right, first line: Chinampas System – Mexico, C. Rey Hernández; Kampung Naga – Indonesia, A. Prestasia and B. Kim; second line: Ksókong Tsùn Irrigation System – Taiwan, M. Lin).

Details – Technical drawings (schemes and diagrams) and pictures of water works showing the spatial composition of the water flow, to understand more about the making of the traditional water system (design). Furthermore, drawing details reveals the craftsmanship and the materials employed. In the eldest examples, the materials often come from the same site or region of the TWS.

Values - a list of values derived from the analysis of the project. These values are based on the PhD work of G. Rivero- Lamela and revised by I. Bobbink. This part needs further development and critical review since this reflection fosters the ambition to learn from the past to improve the future.

Lessons to learn: Insight and awareness on water heritage, connections and similarities from observations. The interest lies not only in the objects *per se* but also in the tradition, the coexistence of tangible and intangible heritage. The main purpose of the lessons derived from the analysed water systems is to be applied to inform new designs.

LIMITS OF A DESK-BASED RESEARCH ON *TRADITIONAL WATER SYSTEMS*

The whole research on TWS is majorly based on second-hand sources, consulted and studied diligently by students. Apart from a few examples (e.g. Kampung Naga - Indonesia, Fishing Valleys - Italy, The Roman Aqueducts – Italy), field inspections, surveys and interviews could not be directly collected on-site and this constitutes, unfortunately, the biggest shortcoming of the research so far. The three points below need to be addressed further:

1. Lack of first-hand data collection (interviews, surveys, site visits, etc.).
2. The systems' understanding results incomplete because of the scarcity of published and established information. Only recently scholars have considered many of these traditional water infrastructures, especially those which are that relevant to get their structures and elements codified. The combination of the first and second points implies that full comprehension is compromised because TWS are strictly connected to their active uses: to visit and see these systems means to understand them and receive direct explanations from those people who use them. A way to overcome and improve these constraints would be to promote publicly the research, apply for funds and allocate them for supporting students' expenses concerning site visits and surveys.
3. Lack of time, since the research on the TWS is part of the students' graduation year. Students have to develop a self-formulated assignment with a certain degree of complexity by enhancing or creating a composition in which a circular water system plays a key role and at the same time conduct semi-autonomously the research on TWS. In this case, likewise, funds would potentially open a PhD position whose candidate could coordinate full-time the research, being able to supervise and edit the students' results.

Besides the described focus on analysing TWS spatially, other aspects like economic, administrative and political contexts are not discussed. While being aware of the significant impact on the approached water systems, nevertheless, studying these social conditions stands beyond our expertise and requires more research and involvement of other disciplines.

THE ROLE OF THE LANDSCAPE ARCHITECT

The crucial role of the Landscape Architect^d is to plan and design urban and rural landscapes in space and time, based on the natural characteristics, historical and cultural values of the area. To do so, Landscape Architects refers to aesthetic, functional, scientific and management methods and principles, with appropriate use of both natural and manufactured techniques and materials. The Landscape Architect must possess the ability to create and maintain landscapes that meet human and natural needs and technical requirements, taking appropriate account of the need to preserve both the environmental and cultural heritage.

Therefore, within the specificity of the research on TWS, it is important to define clearly the role of the Landscape Architect and the required perspective. The Landscape Architect must be able to interpret and decode the water systems considered, understand the physical geography and those natural elements characterising the surrounding environment, read the anthropic formations, the architectonic settlements and interventions on the landscape, and finally work on the opportunity of seizing the best elements of these systems and integrate the practices within well-performing new designs. This consideration reflects the IFLA (International Federation of Landscape Architects) definition of the profession of Landscape Architects stating that architects should “plan, design and manage natural and built environments, applying aesthetic and scientific principles

to address ecological sustainability, quality and health of landscapes, collective memory, heritage and culture, and territorial justice. By leading and coordinating other disciplines, landscape architects deal with the interactions between natural and cultural ecosystems, such as adaptation and mitigation related to climate change and the stability of ecosystems, socioeconomic improvements, and community health and welfare to create places that anticipate social and economic well-being”^c.

In particular, as confirmed by the TWS exercise, Landscape Architects should “conduct research and analysis to develop sustainable landscape design, planning and management practices, theories, methods and development strategies to promote green infrastructure, the sustainable management of natural, agricultural, rural and urban landscapes and the sustainable use and management of global environmental resources” as well as “collect and document data through site analysis, including an appreciation of indigenous practices, landform, soils, vegetation, hydrology, visual characteristics and human-made and managed features and managing digital technologies and representation of spatial systems.” This to proceed further by “developing and managing the landscape by carrying out actions, preparing, and implementing projects for heritage protection, preservation of natural and cultural landscapes, rehabilitation of degraded landscapes, and new development through a process of design, planning, management and maintenance” [2].

CONCLUSIONS

Considering the analysed TWS, despite their historic, geographic, climatic and landscape differences, they have been conceived and constructed by an accurate comprehension of the landscape, respecting their seasonal and cyclical rhythms. Often without the help of mechanical or electrical devices, ancient civilizations were able to bring fresh and drinkable water to their cities, storing and recycling it, flood or drain their fields and they could even build new land in the middle of large water bodies. The great ability behind these astonishing actions was the care and understanding of the territory these people lived in. The care, knowledge, maintenance and adaptation of these precious water systems made it possible for civilizations to prosper over centuries without affecting or damaging irreparably the landscape natural balance. Back then, humans were in communion and part of the landscape itself. Many researchers are aware of this and they are revealing the hidden knowledge of indigenous people, for example as it is illustrated in the book “Lo—TEK. Design by Radical Indigenism” by Julia Watson. The author, with the help of extremely detailed drawings, identifies resilient infrastructures developed by indigenous people through T.E.K., i.e. Traditional Ecological Knowledge.

During the last summit of the Intergovernmental Panel on Climate Change (IPCC) in Stockholm, the latest climate assessment report was presented, declaring “highly probable”, with an index of 95%, that human activities, i.e. greenhouse gas emissions, aerosols and land-use changes, are the main causes of global warming [9]. The frequent floods in northern Europe and the devastating fires all over the world are the most evident signs of the ecological crisis that has been raging in recent years. These problems are mostly related to a gradual disappearance of activities that respect the ecosystem and its natural cycles without putting economic profits upfront. Some countries, like the Netherlands for example, start to understand that the upscaling and rationalisation of water management causes its complications.

In the current climate crisis, the importance of developing an integrated approach by combining strategies and tools of water management, while including ecological, sustainable and spatial qualities, and involving the users becomes evident. In TWS research, carried out by the students, all these concepts emerge: although these landscape systems are distant not only in time but also geographically, they are all united by a common understanding of the territory (through geology, climate, topography, soil etc.). Their designers and creators have transformed the landscape and adapted to new circumstances. Because of the slow transformation process, ecology is more likely to adapt to the change. Ancient communities, from Ancient Romans to Australian aborigines, have everlasting and intrinsic relationships with their territories and nature, showing a visceral attachment to their lands and waters. This connection has resulted in sophisticated place-based knowledge being developed and acquired through generations [1, 8]. TWS clearly show how, in many cases, this results from systems of practices, knowledge and innovations that support the conservation of biodiversity, with associated spiritual, social and cultural values [5, 8]. The ability to assess the impact of different interventions on spatial quality, pondering the future spatial development of the environment without contaminating its intrinsic attributes, is becoming essential. By developing the illustrative method and expanding it with the learnings from the landscape biography, this work provides the rediscovery of the human belonging to the landscape.

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ENDNOTES

^a All graduates of the Landscape Architecture master track (Faculty of Architecture and Built Environment, TU Delft) take part in the 'Flowscapes' studio. *Flowscapes* explores infrastructure as a type of landscape and landscape as a type of infrastructure.

^b Most of the Traditional Water Systems analysed are collected here: <https://circularwaterstories.org>

^c The word “biography” concerning the landscape was introduced by the American geographer M. S. Samuels in 1979 in his article “The Biography of Landscape”. The archaeologists Kopytoff and Appadurai (1990) reintroduced the term in two well- conceived articles “The social life of things” and “Cultural biography”. Dutch scientists T. Spek (2004) and J. Kolen (2005) contributed with their PhD researches. Today this method is widely used in Dutch practice to analyse the rural context.

^d The paragraph reflects and reports from the teaching program and methodology developed during the last decade at the Landscape Architecture master track (Faculty of Architecture and Built Environment, TU Delft).

^e In turn, the IFLA definition about the profession of Landscape Architect it is based on the existing definition by ISCO/08 International Standard Classification of Occupations, an International Labor Organization (ILO) classification structure for organizing information on labor and jobs. The current version was published and adopted in 2008.

THE EFFECT OF MOISTURE ON THE TENSILE STRENGTH, STIFFNESS AND ULTIMATE STRAIN OF BIDIRECTIONAL FLAX FIBRE REINFORCED EPOXY

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ABSTRACT

This study aimed to determine the effect of a wide range of equilibrium moisture content levels on the strength, ultimate strain and the relationship between the stiffness, moisture content and strain of bidirectional woven flax epoxy composites in tension.

The tensile tests have been performed based on the ISO 527-4[1] standard. SR Infugreen810 epoxy resin and SD 8824 hardener from Sicomin were used as the resin system and reinforced with AmpliTex™ 5031-2 balanced 5-harness satin weave. The specimens were conditioned to a wide moisture range from dry to very wet with six different equilibrium moisture levels.

The experimental results show that the strength and ultimate strain both have a positive relationship with the equilibrium moisture content of the specimens. The ultimate strength increased by 35% for 98% relative humidity (RH) conditioned specimens compared to oven-dried ones. The strain at rupture was 1,06% for oven-dried specimens and increased to 2,60% at 98% RH. These specimens showed for both strength and strain a linear relationship with the moisture content. Immersed specimens showed a lower performance compared to this positive trend. The evolution of the stiffness showed a more complex behaviour, in general, the stiffness decreased with increasing moisture content. Very dry specimens initially showed a short increase in stiffness. Wetter specimens showed a smooth transitioning between a rapidly decreasing stiffness in a first stage and a slower second stage. Specimens with very high moisture showed a large initial decrease in stiffness but increased again with strain after a minimum.

KEYWORDS

Flax, epoxy, composite, moisture, tension

INTRODUCTION

Fibre reinforcement, or composites in general, have been used for many thousands of years already. From simple reinforcement of mud with natural fibres to more complex composites applications in later periods, such as the composite bows used by the Parthian mounted archers. Early development on the modern matrix polymers and high-performance fibre reinforced polymer (FRP) composites started in the early part of the 20th century. Initially, FRPs used natural fibres to reinforce polymer matrices. Later the synthetic fibres such as glass fibre and carbon fibre were primarily used.

The large scale usage of synthetic fibres in FRPs continues to this day. This puts strain on the supply of finite resources such as oil and sand. To reduce our carbon footprint and lower our dependence on extracting finite resources, different materials are investigated as replacements. An interest is (again) placed in natural fibre reinforced polymers (NFRPs). The development of renewable and low embodied energy natural fibre reinforced polymers could be part of a solution for a sustainable future.

Currently, NFRP composites are already applied in some non-loadbearing applications such as interior panelling in the automotive industry and various consumer goods. A big focus is on the application of flax fibres for NFRPs. A great property of flax fibre reinforced polymer (FFRP) composites is that it has an excellent stiffness to weight ratio. It also has decent strength, and it is locally available in western Europe. Especially the high specific stiffness makes it a good material for many applications.

Few examples are known in which FFRP composites are used as a primary loadbearing material, even though its potential is good. One of the key aspects or drawbacks of the material is its hygroscopic behaviour. Flax fibres are highly hydrophilic and moisture has a large, mostly negative, impact on the performance of FFRP. More knowledge is required on the performance of the material before it can be properly used as a loadbearing material.

Most of the research on the effect of moisture on natural fibre reinforced composites is done on unidirectional reinforced composites. Woven fabrics are physically different as the yarns are inherently curved due to the weaving process. This difference in configuration and combined with the plasticising effect of moisture on the components might result in a different response of the material when a load is applied. This research aimed to quantify the effect of a full range of equilibrium moisture contents on the tensile strength, ultimate tensile strain and stiffness as a function of moisture content and strain of 5-harness satin weave flax fabric reinforced epoxy (FFRE). This was done in the context of the OPZuid Living Lab: Structural Health in BioBased Constructions project and the Interreg Smart Circular Bridge Project.

METHODS

Material and Sample Preparations

The flax fibre reinforced epoxy specimens were prepared from a laminate plate that was made using a vacuum-assisted resin transfer moulding process. This specific setup used a glass-bottom plate and a flexible top film as mould surfaces. Using sealant tape, the inner volume between the glass and flexible top was sealed from the environment. On one side, through holes in the film, a pump was used to pull the volume under a vacuum. On the other side, at the supply side, the resin was allowed to flow in. Using the pressure difference, the resin flowed through the preform and filled all the voids with resin. After the curing reaction of the epoxy finished, the fibres and matrix formed a solid new material. A schematic representation of the setup can be seen in the cross-sectional drawing of Figure 1.

The epoxy matrix was created using SR Infugreen810 epoxy resin mixed with SD8824 hardener from Sicomin, which is meant for infusion processes. Four layers of AmpliTex 5031-2 5-harness satin flax fabric from Bcomp were used as the reinforcement for the resin. The fabric was cautiously cut from the roll by hand, to prevent yarns from detaching. The four layers of fabric were first dried in an oven at 105 C [2] to remove most of the moisture from the fibres while limiting heat-related degradation. The four layers of fabric were placed as straight as possible on top of the lower mould. The lower glass mould surface was coated with the semi-permanent release agent Chemlease 2185 according to the manufacturer's application instructions. Peel ply, flow mesh, infusion spiral, connectors, sealing tape, vacuum film and flow lines were added to the infusion setup in the configuration as shown in Figure 1. The placement of the fibres and the subsequent assembling of the infusion setup was done as quickly as possible to limit the moisture sorption due to exposure to ambient conditions after removing the dry fabrics from the oven. It was completed within 15 minutes. After completing the setup it was checked for leaks for 10 minutes while under vacuum. An EC-4 vacuum pump with a maximum pressure difference of -0,980 atm together with a catch pot was used. After the infusion finished, the plates were subjected to a post-cure at 40 C for 15 hours while still on the mould.

The whole process resulted in the creation of two-millimetre-thick flax epoxy plates of 280mm by 333mm. Six of these plates were produced for the experiment. The number of plates was chosen as six because this is also the number of moisture conditions used for the experiment, allowing for equal distribution of the specimens over the different moisture conditions.

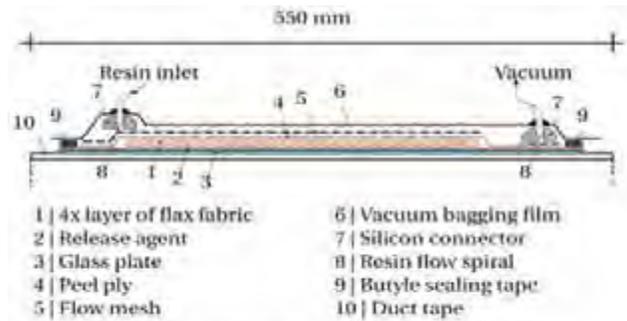


Figure 6.4: Setup for vacuum infusion process

Figure 1. Section of the infusion setup with annotation of the different parts

The tensile specimens used had a rectangular shape and measured 250 by 25 by 2 millimetres. These are defined in the ISO 527-4[1] standard as ‘type 2’ specimens. Type two was used because the dogbone shape is unsuitable for testing bidirectional continuous fibre reinforced composites. The specimens were cut from the plates using a common bandsaw. A custom fixture was used to reduce potential delamination stresses on the specimens during cutting. A total of six plates were manufactured, and 11 specimens were cut from each plate. This resulted in a total of 66 specimens. Slight deviations in the manufacturing process could result in differences in mechanical performance. To alleviate any potential effects of this on the test results the six produced plates were equally divided over six different moisture condition groups. These groups were named: ‘Oven dry’, ‘33% RH’, ‘54% RH’, ‘75% RH’, ‘98% RH’, ‘Immersed’. This configuration resulted in a full range of moisture conditions with roughly similar spacings between the values.

The volume fraction of the constituents could not be determined with the commonly used burn-off method, since flax will disintegrate at high temperatures. The volume fractions were instead calculated using the average areal density of the fabric, the density of flax fibres and epoxy matrix, the surface area and the total weight of the specimens.

For measuring the density of the epoxy matrix five small epoxy samples were made using degassed resin. Any imperfections in the specimens were cut out, sanded and lightly polished. The density of the specimens was measured and calculated based on Archimedes’ principle using a Mettler Toledo AT400 analytical scale with a bottom suspension platform while the specimens were immersed in distilled water at 20 C.

The volume of the oven-dry flax fibres was measured using a helium gas pycnometer, which measures the volume of material based on Boyle’s Law. An AccuPyc II 1340 helium pycnometer from Micromeritics was used. Weight measurement was done on a Mettler Toledo AT400.

The areal density of the fabric was measured by cutting patches of 70 by 70 mm precisely in between the yarns. Length measurements were done with a simple ruler. Weight measurement on the fabric was done as soon as they left the oven, using a Mettler Toledo AT400 analytical scale.

Moisture Conditioning

Each of the six conditioning groups contains 11 specimens for testing. Specimens from the group that were dried in an oven at 105 C are referred to as ‘OD’ (oven dry). Those conditioned to an equilibrium moisture condition in relative humidity of 33%, 54%, 75% and 98% are referred to as ‘33RH’, ‘54RH’, ‘75RH’ and ‘98RH’, respectively. Specimens from the group that were immersed in water are labelled ‘IM’. The moisture content (MC) is defined as displayed in equation 1 below. Where w is the wet weight and d is the dry weight of the specimens.

$$MC_{dry\ basis} = \frac{w-d}{d} \tag{Eq. 1}$$

Moisture conditioning started with first drying the FFRP. This was done at a temperature of 105 C, to prevent significant thermal damage to the fibres[2]. The oven-dry weight of the specimens was taken as having no moisture content.

The specimens had to be conditioned to contain specific amounts of moisture. This was achieved via drying, exposure to relative humidity and immersion in water until equilibrium was reached with these conditions.

Specimens from the OD group were tested after removing them from the oven and allowing them to cool down to normal laboratory temperature, 20 C in this case. Specimens from the second cluster, which were 33RH, 54RH, 75RH and 98RH, were conditioned to intermediate moisture levels. These RH values were achieved with the use of specific saturated salt solutions[3] in demineralized water at a stable temperature. See Table I for the list of salts and their corresponding relative humidity at.

Table I: Relative Humidity from Saturated Salt Solution

| Salt | | RH [%] |
|--------------------|-----------------------------------|------------|
| Magnesium Chloride | MgCl | 33,07±0,18 |
| Magnesium Nitrate | Mg(NO ₃) ₂ | 54,38±0,23 |
| Sodium Chloride | NaCl | 75,47±0,14 |
| Potassium Sulfate | K ₂ SO ₄ | 97,59±0,53 |

The specimens that should be conditioned by relative humidity were placed in airtight containers that were made specifically for this test. These containers were located in a climate-controlled room that was kept at 20,4 C. The relative humidity was controlled by specific salt solutions located at the bottom of the barrels. A small fan was present to get sufficient air circulation. An illustration of this setup can be seen in Figure 2.

The IM specimens were conditioned by immersion in demineralized water. This resulted in the absorption of large amounts of water inside the specimen, but also on the surface. For the weight measurement, this moisture was first wiped off with absorbent paper towels.

Whenever possible the specimens were measured once or twice a week by measuring the weight on an AT400 Mettler Toledo analytical scale. During the majority of the Covid19 lockdown, it was impossible to measure changes in mass, thus no data is available for a large portion of the absorption process. In the week before the mechanical testing, the specimens were weighed three times to confirm that the mass remained constant and thus that equilibrium was reached.

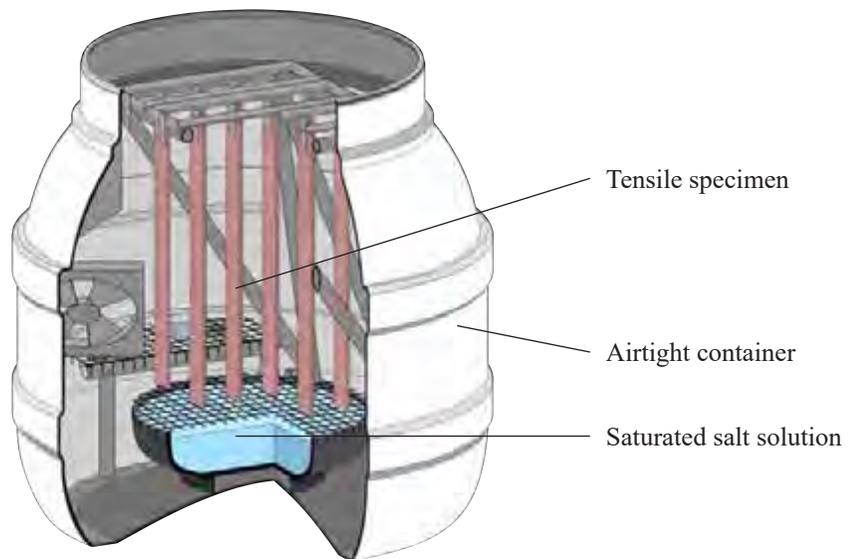


Figure 2. Conditioning chamber for relative humidity

Mechanical Testing

The tensile tests were performed by applying a monotonic static loading to the tensile specimens. These specimens were fixed with mechanical wedge action tensile grips. The loading was applied by an Instron 5985 universal testing machine with a 250kN loadcell. The strain was measured in the direction of the load via an optical extensometer from the same brand. This measured the strain or displacement data of the specimen with digital imaging processes that track the location of two white gauge markers located at a distance of 50 mm in the middle of the mould side of the specimen. The crosshead movement was displacement driven at two millimetres per minute. The clamping length on both sides was 70 mm. The frequency of data acquisition was five Hertz.

Analysis and Measurements

The cross-sectional area was not consistent along the length of the specimens. This was caused by the usage of one flexible mould surface. It was deemed appropriate to approximate the width and thickness at the failure location by interpolating the measured width and thickness at three points along the longitudinal axis. The width was measured at three points, while the thickness was measured at six points, at similar locations. See Figure 3.

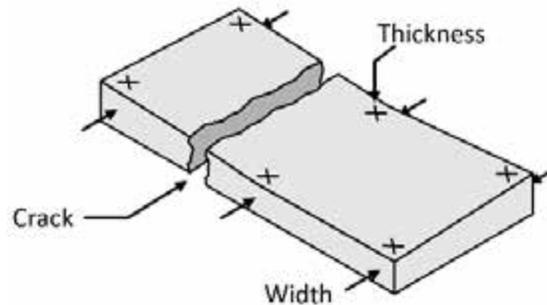


Figure 3. Schematic visualisation of the width and thickness measurement before testing of the specimen

The thickness and width were measured using a vernier calliper. After fracture of the specimens, the location of the crack was used for linear interpolation between the relevant points to calculate the approximate cross-sectional area at the failure plane. These dimensions were measured from the oven-dry state of the specimens.

The stiffness to strain curves were calculated by taking the derivative of 4th, 5th or 6th order polynomial functions that were curve fitted using MS Excel to the stress-strain data for individual specimens. The best-fitting polynomial for each specimen was chosen. Curve fitting was required because the stress-strain data from the optical sensor was slightly jittery. This made it impossible to correctly derive the stiffness directly based on the stress-strain data.

For normal applications of this material in structures, for the serviceability limit state, the deformations will not reach into the end portion of the measured strains. The stiffnesses in the lower ranges are more representable for their behaviour in structural applications. The (predominantly non-elastic) stiffness was defined based on the difference between two points on the stress-strain curve, see equation 2 below.

$$k = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \quad (\text{Eq. 2})$$

Where σ is the stress and ε is the strain. Subscripts 1 and 2 indicate points on the stress-strain curve, where subscript 2 refers to the point with the highest strain value.

RESULTS

Volume Fractions

As previously described, the areal density of the fabric and density of both the epoxy and fibres were needed to determine the volume fractions. The average areal density of the dry fabrics was . The average density of the epoxy was . The average density of the dry fibres was . Calculating the volume fractions gives that the average fibre volume fraction of the composite was 24,7%, the matrix volume fraction was 65,8% and the void fraction was 9,6%.

Moisture Content

The moisture content of the OD specimens were per definition 0%, as was stated earlier. The moisture content of the specimens that were conditioned with relative humidity and water immersion were taken when moisture equilibrium was achieved. Table II shows the resulting averages and the distribution of the moisture content.

Table II: Resulting Equilibrium Moisture Content

| Sample group | Moisture content [%] | Standard deviation [%] |
|--------------|----------------------|------------------------|
| OD | 0 | - |
| 33RH | 1,60 | 0,176 |
| 54RH | 2,98 | 0,143 |
| 75RH | 4,71 | 0,165 |
| 98RH | 8,97 | 0,297 |
| IM | 15,9 | 2,17 |

The equilibrium moisture content is plotted as a function of the relative humidity in Figure 4. The specimens conditioned in water were put in the graph at 100%, although this exposure condition is not the same as the actual 100% relative humidity.

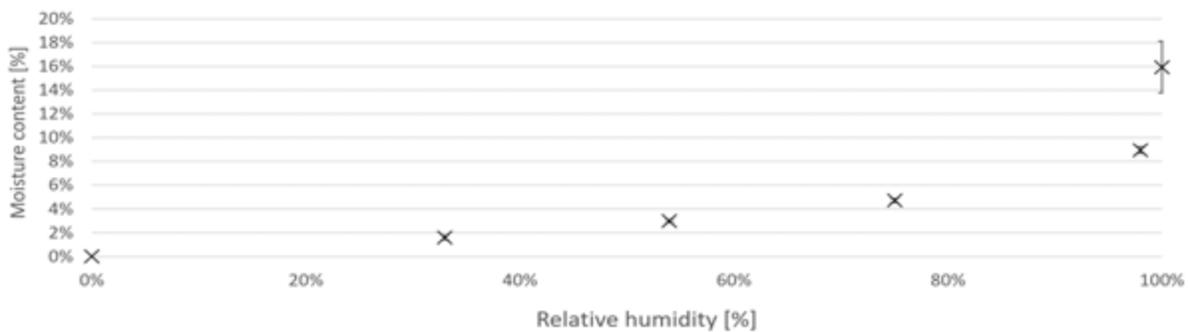


Figure 4. Increase of the moisture content in relation to the relative humidity and water immersion. The error bars represent the standard deviation.

Tensile Strength

In table III the average stress at failure (is displayed for each of the six different conditioned groups. In Figure 5 the underlying values for the average stress at failure are plotted as dots. The curves leading up to these points represent the average stress to strain behaviour during the loading process. Plotting of the curves stops at the point of the first fracture of the group of specimens.

Table III: Average Strength and Their Distribution at Fracture

| Sample group | Average strength, $\sigma_{u,avg}$ [MPa] | Standard deviation [MPa] |
|--------------|--|--------------------------|
| OD | 92,6 | 11,4 |
| 33RH | 104 | 6,04 |
| 54RH | 114 | 6,58 |
| 75RH | 112 | 7,69 |
| 98RH | 125 | 7,04 |
| IM | 118 | 10,6 |

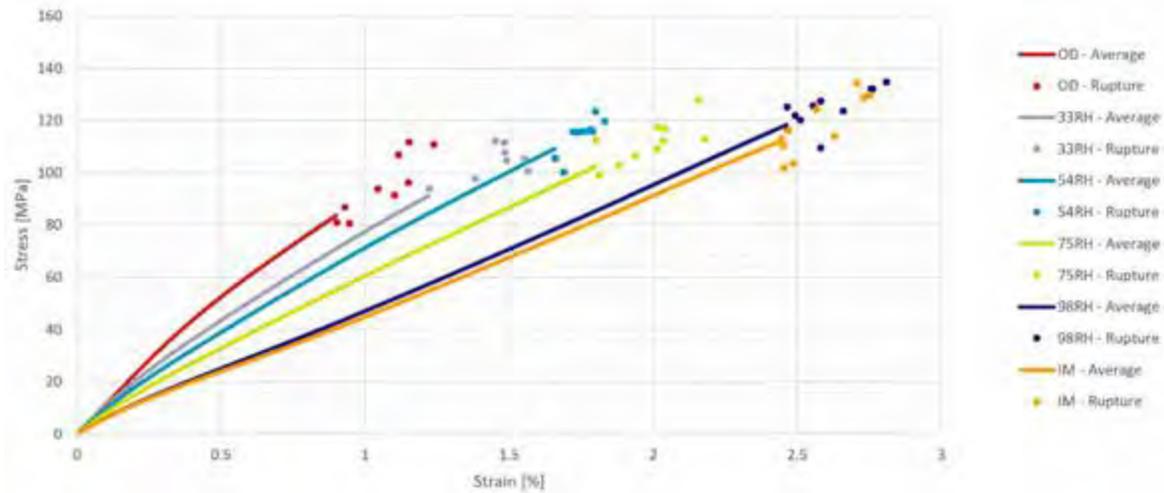


Figure 5. Stress to strain curves and strength

In Figure 6 the relationship between the strength of the specimens and the moisture content is displayed. Notice that the spread in moisture content for the dry and relative humidity conditions is low, while the spread in strength figures is rather high. Linear regression was used to capture the data in a formula. This results in the following formula, $\sigma_u = 99,5 + 292 \cdot MC$, with a R^2 value of 0,53.

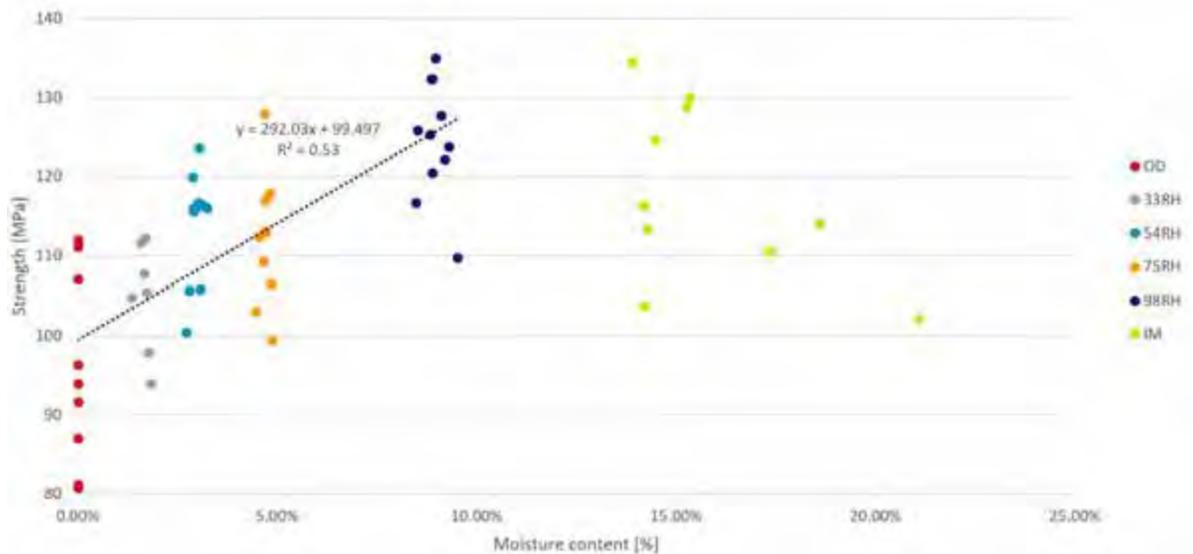


Figure 6. Strength to moisture content

Strain

The ultimate strain and its distribution are displayed in Table IV. The underlying data points are plotted in Figure 7. A linear regression analysis that was done on the ultimate strain to moisture content data from oven dry to 98% relative humidity resulted in the following formula: $y = 16.534x + 1.166$, with an R^2 value of 0,9427. The value of the immersed specimens was not taken into account in the regression analysis.

Table IV: Average Strain Level and Their Distribution at Fracture

| Sample group | Average ultimate strain, ϵ_{avg} [%] | Standard deviation [%] |
|--------------|---|------------------------|
| OD | 1,0618 | 0,10908 |
| 33RH | 1,4527 | 0,10232 |
| 54RH | 1,7429 | 0,05461 |
| 75RH | 1,9857 | 0,12251 |
| 98RH | 2,6018 | 0,11886 |
| IM | 2,5669 | 0,11879 |

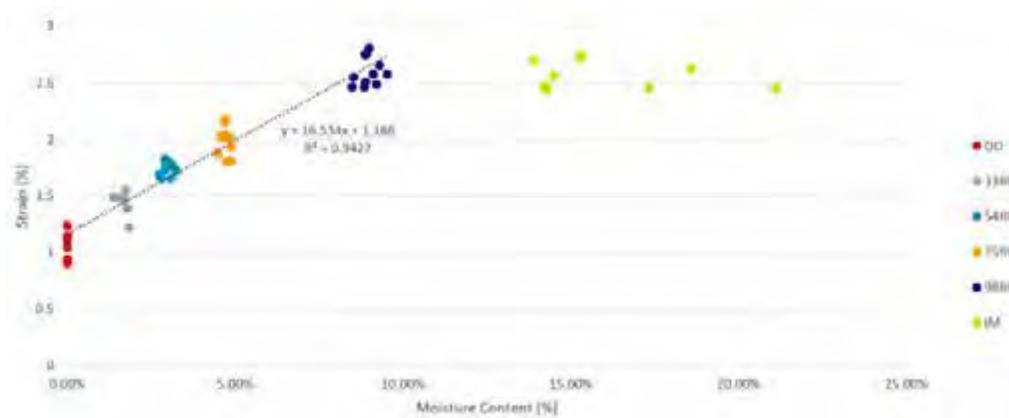


Figure 7. Maximum strain as a function of the moisture content

Stiffness

The secant modulus, which is the Young's modulus for a very small portion of the strain, was calculated between 0 and a stress value of around or below 5 MPa, where the stress-strain behaviour appears linear. This data is visible in Table V. The evolution of the stiffness at higher strains is displayed in Figure 8. The graph starts at the calculated Young's modulus at zero strain and the curves that are plotted at higher load levels are the derivatives of the function fitted to the experimentally obtained stress-strain data. The plot of the stiffness shows three distinctly different curves. For dry specimens, an initial increase in stiffness is observed, after which a gradual decrease occurs. For the medium wet specimens, the stiffness decreases in two stages with different slopes. For very wet specimens an initial decrease happens till a point of rigidification, after which the stiffness increases again.

Table V: Secant Modulus and Their Standard Deviation

| Sample group | Average Secant modulus [MPa] | Standard deviation [MPa] |
|--------------|------------------------------|--------------------------|
| OD | 10812 | 1077 |
| 33RH | 10725 | 975 |
| 54RH | 10123 | 1070 |
| 75RH | 8862 | 1062 |
| 98RH | 6537 | 743 |
| IM | 7212 | 986 |

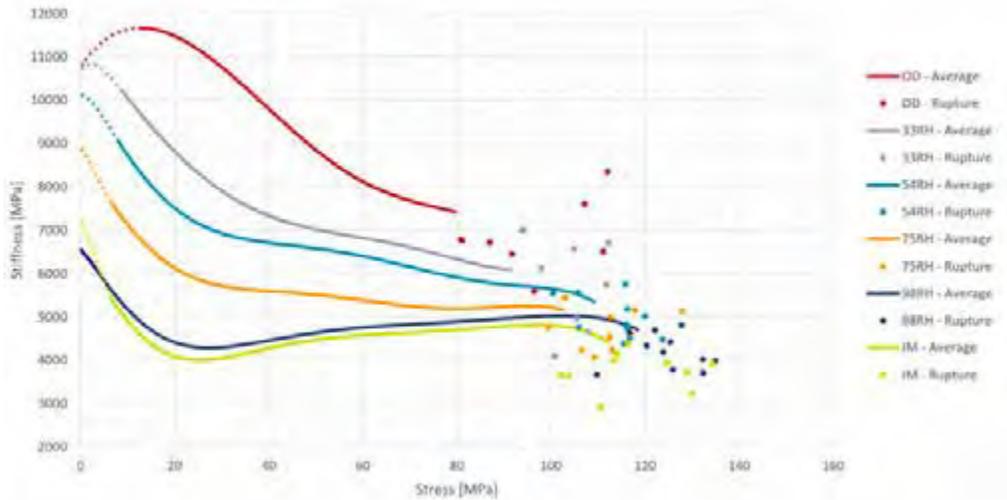


Figure 8. Stiffness to stress and fracture

The elastic range of the material is very short, thus the stiffness changes when loaded to higher levels. When considering the application of this material as a loadbearing material for medium-sized pedestrian bridges 5 MPa was assumed to be a reasonable estimate for the characteristic semi-permanent loading state of a plant fibre reinforced polymer bridge, while 20 MPa is assumed to be the upper limit for the load to prevent excessive creep[4]. Figure 9 shows the stiffnesses calculated between stress ranges starting from 5 MPa up to 20 MPa, with 5 MPa increments. A quadratic function was fitted to the data points relating the defined stiffnesses to the moisture content.

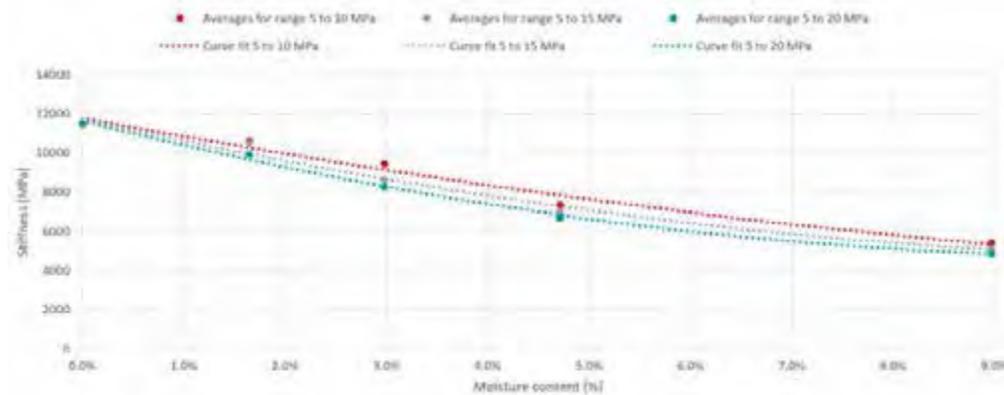


Figure 9. Curve fit of the stiffness to the moisture content in practical stress ranges

DISCUSSION

Moisture Content

The oven-dry specimens were dried at 105 °C, at this temperature some bound water remained inside. Nevertheless, this state was taken as 0% moisture and the reference point for specimens with higher moisture content.

The amount of free water was likely higher for the high RH and immersion specimens due to the relatively high void fraction and low fibre volume fractions, compared to the expected values for vacuum-assisted resin transfer moulding (VARTM) processes. It likely contributed to the large standard deviation of moisture in the immersed specimens as more space is available inside the composite for free water to occupy.

Strength

From other research, it is already known that the moisture content affects the strength of the plant fibres and related composites. Single short fibres see an increase in strength with increasing moisture content[5] or have a peak in strength around 70% RH[6], [7]. Tests performed on flax epoxy composites by Abida et al[8] showed similar results to those obtained in this research. However, other research shows a decrease in the strength of flax polymer composites with higher moisture content[9],[10], both were done with UD composites.

A possible explanation for the observed increase in strength is the straightening of the curved yarns in combination with the plasticization of the fibres. In a dry condition, the fabrics would mostly be fixed in place. Water makes the fibre more flexible and could allow them to transition from their wavy woven pattern into a straighter alignment. This is a better load path and would increase the maximum load the fibres can resist before breaking. The void content, which is higher than normal might also play a role here, as it would decrease the resistance to straightening the fibres. The increase in strength from the straighter load path might have a greater impact than the reduction in strength due to the plasticization of either the fibre or matrix. The amount of data available is insufficient to determine the actual mechanism.

Strain

The maximum strain of composite specimens with very high moisture content are in close agreement with the values found by other researchers[8], [9], [11], [10], the maximum strain increases with increasing moisture content. At lower levels of moisture content, the related maximum strains seem to differ. In terms of strain, the results from Moudood[11] are similar to ours. Whereas in the case of Abida[12] the strain values of dry specimens were clustered around 1%, which is lower than our result. Interestingly, our strain to MC data is almost perfectly linear. In the case of Abida[8] and Moudood[11] a linear relationship is plausible but not as obvious.

The plasticising properties of water allow more movement of the polymer chains of the flax, and to some extent also the epoxy. In general, more water thus means a higher maximum strain. It is expected that the higher increase in strain is partially due to the straightening of the yarns, which were originally curved due to the 5HS weaving pattern. Higher plasticity of the flax fibres and the polyester matrix could perhaps allow for this movement of the fibres. Based on the results of other researchers it is likely that the interaction between the plasticity of fibres and matrix, together with the response of woven reinforcement fabrics just happen to result in a linear relationship for the strain.

Stiffness

The general form of the stress-strain curve of a flax fibre[13], and similarly that of UD flax epoxy composite starts with a very short linear portion, followed by a rapid decrease in stiffness. After this sudden decrease, the stiffness slowly increases with the strain until a second linear portion is reached. The drop and subsequent increase in stiffness are often contributed primarily to the movement and reorientation of microfibrils although other factors also play a role.

When comparing our results to those of Abida et al[8] it is visible that their stiffness curves are very similar to ours. In their article, a possible explanation for this phenomenon is sought with the rearrangement of the microstructure of flax fibres. They propose that the rigidification stress drop indicates that the reorientation of cellulose microfibrils is enhanced with water absorption for higher strain. An interaction between moisture and straightening as well as untwisting of the fibres could be the reason why no clear point of rigidification is observed as seen for hemp fibres[14]. In our case, the fibres likely had a large amount of moisture available to interact with the cellulose microfibrils and the fibre as a whole which might have contributed to the increase in stiffness.

It is uncertain why the initial stiffness of the immersed specimens was higher than those from 98% RH. A lower stiffness was expected for the immersed specimens because a larger amount of moisture was present that could act as a plasticiser as well as it can cause damage to the integrity of the composite.

In some cases, a small 'bump' with a higher stiffness was observed below 0,25% strain. For the secant modulus, this influence was ignored. The elastic range was difficult to pinpoint, due to the slight deviations that are probably caused by the optical extensometer. It has to be noted that due to the inconsistencies with the optical extensometer the correct values for the stiffness were difficult to calculate in the low strain range, generally below 0,2% strain, as well as at fracture.

CONCLUSION

The goal of this research was to determine the effect of moisture on the ultimate tensile strength, ultimate tensile strain and the relation between the stiffness and strain of the flax composite. The conclusion can be drawn that the tensile strength of bidirectional 5-Harness satin flax reinforced epoxy has a positive relationship with the moisture content. The ultimate tensile strength increased from 92,6 MPa when in a dry state up to 125 MPa for the specimens when conditioned at 98% RH. In percentages, this is a 35% increase. The strength at maximum MC was at 118 MPa.

From the results, it is also found that the ultimate strain linearly increases with increasing equilibrium moisture content, from the dry state up to 98% relative humidity. It increased from 1,06% up to 2,6% respectively. This shows a 145% increase in maximum strain compared to the dry state. Linear regression on this section showed , in which is the strain at failure.

The stiffness shows nonlinear behaviour, which can be divided into 3 different types of curves. Specimens that were very dry initially increased in stiffness during the initial loading after which a peak was reached and afterwards the stiffness reduced with increasing load. For intermediate moisture contents, the stiffness showed a rapid decrease in the beginning, and later the rate of reduction slowed down. Very wet specimens showed a very rapid decrease in stiffness at the start. At around 25 MPa an inflexion point was visible, after which the stiffness slowly increased with increasing load.

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URBAN DISTRICT HEATING NETWORK DELIVERY: LESSONS LEARNT FROM THREE CASE STUDIES – COPENHAGEN, STOCKHOLM AND HELSINKI

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ABSTRACT

This research explores the implementation of large-scale district heating (DH) networks in Copenhagen, Stockholm, and Helsinki in order to draw lessons on how to implement efficient DH networks at scale. The heating sector has the largest share of energy consumption globally, which accounts for a third of global carbon emissions. Due to its strong dependency on fossil fuels and the low cost of implementing individual heating systems, such as gas boilers, it is considered to be one of the most difficult sectors to decarbonise.

DH has the potential to deliver on decarbonisation and renewable energy targets in the heating sector. Its capacity to use a wide variety of low carbon heat sources, such as industrial waste heat, ocean and river source heat, solar thermal and geothermal heat, is seen as a major advantage in increasing supply diversity and reducing reliance on fossil fuels. However, DH can be a complex technology to implement, requiring the consideration of multiple factors, the collective network of actors involved and the interaction between various elements of the socio-technical system.

This research seeks to provide insights into how cities implement large scale DH networks with a view to finding best practices and effective measures that can overcome the main barriers limiting the uptake of DH networks. The implementation strategies of DH networks in the case study cities are described and key success factors as well as weaknesses are examined. Drawing on socio-technical transitions literature, this research analyses the institutional, political and implementation strategies integral to the delivery of efficient DH networks. It employs a multi-case study approach using qualitative methods to explore DH network implementation from a socio-technical perspective.

The findings revealed that the implementation of efficient DH networks can be achieved through certain key success factors which include various organisational, technical, social, political and design considerations. Also, heat networks will only deliver increased energy efficiency and climate mitigation objectives if properly designed, implemented and managed. This research will be useful for actors seeking to implement DH to identify strategic directions towards the implementation of efficient DH networks.

KEYWORDS

District Heating, Energy Efficiency, Heating Sector, Heat Decarbonisation,
climate mitigation objectives, Renewable Energy

INTRODUCTION

A growing number of stakeholders and policymakers are becoming aware of the district heating potential and the opportunities it provides in terms of energy efficiency and climate mitigation objectives [1,4,56]. Failures in the past in several regions, as well as a lack of expertise with direct implementation of district heating systems, have raised concerns about the strategies, technical solutions, expertise, policies, regulations, pricing, consumer protection, and financial instruments required to deliver efficient DH systems. This calls for a detailed research analysis on how cities implement DH systems in order to identify/develop effective policies, strategies and regulatory framework that can overcome key barriers and to facilitate more appropriate decision making towards the uptake and delivery of DH systems in urban environments [1].

Heat demand accounts for more than 50% of the world's final energy consumption (across the residential, commercial and industrial sectors) with over 75% of this demand met by fossil fuel, **while only 10% of heat demand is met by renewable energy** [34]. Due to its strong dependency on fossil fuels and the low cost of implementing fossil fuel powered heating systems, such as gas boilers, it is considered to be one of the most difficult sectors to decarbonise [34,35]. Decarbonizing heating is a top priority to achieve a 50% reduction in CO₂ emissions by 2030 and net-zero emissions by 2050 [5,45,58]. The rising need for a reliable, cleaner and more efficient low carbon heat supply and affordable heating has led to increased interest in DH due to the flexibility of integrating various natural and renewable heat sources into the technology as well as its cost effectiveness [16,42]. DH has the potential to play a significant role in decarbonising the heat sector, investing in low-carbon heating solutions will improve air quality while also attracting inward investment, creating jobs, and enhancing social welfare [5,45,58].

This research analyses the implementation of DH networks in three Scandinavian cities to draw lessons on how Copenhagen, Stockholm and Helsinki have successfully implemented large scale DH systems. The aim of this research is to provide a set of basic concepts on how cities implement efficient DH networks by identifying best practices and effective governing measures that can overcome the main barriers limiting the uptake and delivery of DH at scale. The findings of the study are derived from the document analysis of secondary data using a systematic approach to answer specific research questions. Lessons were drawn from the case studies with regards to how intermediary activities can support the development of DH and considerations of various DH policies. This will be useful for key stakeholders and policy makers seeking to implement DH to identify relevant policy design considerations to outline strategic directions towards the implementation of large-scale DH networks.

THEORETICAL FRAMEWORK: URBAN ENERGY SYSTEMS AND THE MULTILEVEL PERSPECTIVE ON SOCIO-TECHNICAL TRANSITIONS

The urgency of climate change mitigation has led to increased research interest on how the transition to a more sustainable low carbon economy can be accomplished. Urban infrastructure studies and its dynamics has become an increasingly significant part of sustainability and low-carbon discourses. Urban energy systems are complex, adaptive systems made up of organisations, policies, technological components and applications which involve dynamic interactions between various actors with diverse roles and interests [7,52]. Several underpinning theories have emerged that use similar concepts but apply different lenses to the transition process. The four main theoretical frameworks include: strategic niche management [48,49,53,54], the multi-level perspective [24,29,30], technological innovation system [6,40,41] and transition management [37,38,51].

The MLP is an analytical framework that builds a conceptual perspective on system innovations and technological transitions that has been used to describe and analyse sustainability transitions in various systems, such as the energy system, transportation system, and the heat and cooling system [26,27]. The MLP posits that socio-technical transitions emerge by the interaction and alignment between three levels of structuration- a level of confined technological niches within a socio-technical system that serve as “protected spaces” and a testing ground for new technologies where innovations can emerge free of the selection pressures of the incumbent regime; a level of socio-technical regimes (for example, the energy system) that provide stable structures and a selection environment for innovations; and, thirdly the socio-technical landscape, which includes cultural norms, values, and relatively stable broader social structures that influence niche and regime dynamics, as well as the socio-technical system structures [24,49].

Using the heat system as an example, slowly changing external factors such as climate change influence the development of the heat system at the landscape level but are beyond the control of individual actors. The existing fossil-fuel-based energy regime is marked by the dominance of certain technological artifacts, networks, cultural meanings, user practices, institutions, market structures, cultural meanings, scientific knowledge, regulatory and frameworks. To reduce carbon emissions, significant

adjustments to current energy systems are required. Consequently, transitions require disruptions in the established order and a whole system reconfiguration with transformational changes not only in technologies, but also in consumer behaviours, policies, infrastructure, production networks, business models and market culture referred to as socio-technical transitions [23,27,28].

The analysis of DH implementation in the cities of Copenhagen, Stockholm and Helsinki intends to contribute to a growing body of research that emphasizes the importance of spatial perspectives and the crucial role of cities and regions in transition processes. Using the multi-level perspective on socio-technical transitions, it focuses on the specific local dynamics of DH implementation: what instruments and strategies have been employed by the case study cities in the implementation of efficient DH networks for sustainable heat production and consumption? What motivations, visions, logic of actions, and actor coalitions shape these place-related strategies? How are local actions and change capacity interconnected with and dependent on multiscale relations such as international regimes and national frameworks? The analysis of the implementation of DH in the case study cities is based on the systematic literature and documentary review of policy documents, academic literature and government publications.

CASE STUDY ANALYSIS: DISTRICT HEATING IN COPENHAGEN, STOCKHOLM AND HELSINKI

Currently, space heating and domestic hot water in Helsinki, Stockholm and Copenhagen is mostly based on district heating systems accounting for 92%, 80% and 98% of total heat demand, respectively [13,22]. The city of Copenhagen has developed a world-class DH network comprised of 21 municipal and community-owned local networks, making it one of the world's largest and most successfully integrated heat network. Copenhagen has an ambition to be the world's first carbon neutral city by 2025, being the world's first capital city to make such commitments, it has developed climate targets and initiatives that are unique in demand [3,20]. The DH network in Stockholm has been in existence for more than 50 years [39]. Stockholm's goal is for the city to become fossil fuel free by 2040 [8,14,15]. The construction of the DH network in Helsinki began in the 1950s, large buildings, such as housing firms and apartment buildings, are connected to the DH network [13]. Helsinki aims to become a carbon neutral city by 2035. Emission reduction has been mainly achieved through lower CO₂ emission factors of the Helsinki DH network [12,50].

Implementation Strategy

Copenhagen, Denmark- Mandatory connections

Local authorities in Denmark carried out infrastructure and environmental planning to establish the geography of DH and natural gas networks which paved way for the installation of DH networks. DH Schemes are created only when they meet the criteria of a standardised assessment, indicating that DH will provide cheaper heat than other available options [10,19]. Planning regulation amendments in 1979 introduced the Heat Supply Act which required municipalities to allocate certain areas to DH, mandating buildings to be connected to the DH network which paved the way for the installation and increase in the coverage of DH considerably. The Heat Supply Act, which was amended in 1994 to include a ban on conversion to electric heating in existing buildings, also banning electric heating in new buildings located within DH network zones. Cooperatives owned by consumers, municipalities, utility companies, or a combination of these are the main ownership structure. This is to maximise technical, institutional and financial efficiency to lower heat costs [19,22].

Stockholm, Sweden- Market Forces

DH was initially developed to improve energy efficiency and air quality, as a response to the oil crisis of the 1970s. **Municipalities owned and operated the first DH systems** in Sweden, introduced in the 1940s, and were also responsible for providing gas and electricity to their residents through municipal utilities. Several DH networks were established in the 1980's and in the 1990's virtually every city and municipality had its own DH network. Initially, DH was regulated on a public-private partnership basis and was governed by the Local Authorities Act (1991). Three principles guided the regulation: equal treatment, cost-based pricing and locality. A new law was introduced in 1996 that deregulated the electricity market, which also included the DH market, enabling the operation of the market-based DH sector [19,22]. Following deregulation, DH ownership is now a mix of municipal limited companies, state-owned, private companies, and publicly-owned [19,22]. Fortum Värme is Stockholm's main DH operator which is co-owned by the city of Stockholm and Fortum Corporation both having an equal share of 50% and equal voting rights. It produces an average of 8 TWh/y, 10,000 clients and direct supply to 6 municipalities [14].

Helsinki, Finland- Established DH Networks

Helsinki has well developed district heating systems, throughout its history, Helsinki DH has always been business based [31]. The DH business is **not directly regulated** and there is no obligation to connect to a DH network in Finland, in most cases connection has been **required locally as municipalities** have imposed DH connection in their city plans. Customers connected voluntarily as a result of the competitive price level. Customers are free to select their own heating method and also switch away from DH to other heat methods without any additional charges. Due to the investment required, DH users usually consider disconnecting from the DH network when district heat exchangers need to be replaced. However, switching from the established DH systems in buildings to other heating systems typically involves a financial implication on the customer as a result of the system change [32,56]. The city of Helsinki is the sole owner of Helen Ltd which is the municipal DH energy company in Helsinki. The company was formed in 1977, when the municipal electricity company and the municipal gas company merged [32,56].

Technical Solutions and Heat Sources

Copenhagen, Denmark

The Danish government has locked-in certain technological solutions through policy, in particular CHP. The Heat Supply Act mandates that plants larger than 1 MW must be operated as combined heating plants, which has resulted in about 80% of district heating being co-produced with electricity. The heat supply is mainly from waste to energy plants, renewable energy and CHP (combined heat and power) plants as well as industrial waste heat from thermal processes [3,60]. While connection by a manufacturer is voluntary, the supply of excess heat is in both operators' and manufacturers' financial interests, which is a successful driver. Several natural gas networks in the city have recently been replaced by district heating, and the heat networks are expanding to supply the city's new urban areas in order to achieve its net-zero carbon targets [3,20].

Stockholm, Sweden

Following the oil crisis, Swedish energy policy prioritised the replacement of oil, primarily with biomass. DH in the city of Stockholm is largely powered by renewables from biofuels, waste heat and energy from waste and electricity [15,19]. The use of surplus heat is voluntary and not mandated by law. Industrial waste heat has played a significant role in the development of DH systems in a number of Swedish cities and towns. Although no incentives or subsidies exist to encourage industrial plants to recover heat, the additional revenue generated by DH operators is sufficient to drive the sale of excess heat [15,19].

Helsinki, Finland.

Helsinki is one of the major cities using district heating in Europe. The building volume of district heated buildings is over 170 Mm³ and floor area over 60 Mm². The Helsinki district heating network operates a combined heat and power DH system with a pipeline of about 1,400 km, which supplies the entire city of Helsinki [13,56]. The production of DH in the Helsinki network is mainly based on coal and gas-fired cogeneration of heat and electricity (CHP). The network has a total district heating capacity of 1,330 MW from two coal-fired CHP plants. In order to achieve the goal of being carbon-neutral by 2035, Helsinki plans to transition away from fossil fuels, towards carbon-neutral DH by incorporating sustainable renewable energy sources into its DH system [13,56].

Policy Instruments and Regulatory framework

Copenhagen, Denmark

Strong planning regulation, as outlined in the Heat Supply Act (1979), combined with national and municipal buy-in, aided in the establishment of a solid foundation for regulating and expanding the network. Direct policy intervention has also aided in the promotion of DH. Municipalities have the authority to impose mandatory connections on new and existing structures, which is network was one of the main reasons for the success of the system. A carbon tax (higher than their European counterparts) was implemented in 1992 to discourage the use of fossil fuels, and oil burners were banned in new construction in 2013 and existing structures in 2016. Financial incentives were implemented to ensure the continued economic viability of DH and CHP. Subsidies and taxes promoted improvements towards increased renewable energy generation [19,22]. National and regional regulation have been relaxed to give local decision-makers complete control over the design, upgrade and approval of their heating systems, heating plans, and projects within their locality [19,22].

Stockholm, Sweden

There is no specific national government policy on DH, rather they provide an overarching policy agenda to transition away from fossil fuels. These policies are often technology agnostic and will not promote DH over other technologies that provide comparable results (e.g. heat pumps). Swedish Government has implemented a **comprehensive collection of policy instruments** and incentives to promote a sustainable and market-based heat supply to drive the transition to low carbon heating (including both DH and heat pumps) [22]. In 2008, the DH Act was introduced by the Swedish Government to protect consumers and improve transparency in the DH sector. Key elements of the Act are include: Investment subsidy programs for biomass CHP were implemented from 1991 to 2002, and tradable certificates for renewable energies were introduced in 2003. A high carbon tax, a tax on natural gas used for heating, a tax on heating oil, and an exemption for renewable energy and combined heat and power production. The introduction of landfill bans on combustible/biodegradable waste in 2002 and 2005, resulted in an increase in heat generated by waste incineration. Between 2006 and 2010, households could receive subsidies to switch from oil to alternative heating systems. While municipalities continue to play a critical role in DH development, their responsibilities and powers have decreased following energy market liberalisation, and heat planning has become less prevalent [11,19,22].

Helsinki, Finland.

There is no DH act in Finland. The Energy Authority promotes energy efficiency through energy audits, consumer education, voluntary energy efficiency agreements, and product eco-labelling and eco-design. The government and participating sectors chose the voluntary approach to avoid introducing new regulations to meet national energy efficiency goals [13]. Fossil fuels are taxed in Finland based on their energy content and CO₂ emissions. Renewable fuels are generally tax-free, to incentivize renewable heat energy generation. Land use procedures are also considered when assessing the potential for heat production in the Helsinki region [13,43]. The prohibition on market dominance imposes certain pricing and cost elements on district heating operators, such as new capacity investments. Third-party access to the district heating network is unregulated and there is no obligation to connect a district heating network . [13,17,19,57].

Pricing and Consumer Protection

Copenhagen, Denmark

The legislation states that the consumer's heat price should cover all necessary costs. This includes production, transportation, financing, and asset depreciation to ensure long-term financial viability for operators. To protect consumers from monopoly abuse, both production and network companies must be non-profit. For greater transparency, each DH company sets annual heat tariffs based on actual expenditures, which are then made public. Since all apartments have sub-meters, users' bills include both usage and fixed costs. In some cases, fixed costs and mandatory connection help vulnerable consumers [19,22,46]. Contrary to popular belief, the not-for-profit rule does not protect consumers from inefficient management or practices. DERA introduced voluntary benchmarking to help with transparency. Most operators use the benchmarking model to compare prices and improve cost-effectiveness. Complaints from private consumers are handled by their DH provider. Unsatisfactory outcomes are escalated to The Energy Supplies Complaint Board (non-sectoral issues) or DERA (regulated issues) while the Energy Board of Appeal is the next level [19,22,46].

Stockholm, Sweden

The 1996 deregulation removed DH's non-profit pricing principle. As a result, some consumer prices increased by more than 15%, which sparked protests and national debate. This was a major impetus for the DH Act of 2008, which focuses on price transparency[19,39,44]. A key argument against price regulation is that DH is part of a larger heating market in which other technologies such as heat pumps compete. In 2013, DH companies and customers began a voluntary price agreement initiative known as Prisdialogen ('PriceDialogue'). Approximately 70% of DH companies have enrolled in the scheme, which requires price forecasts for the next two years to promote transparency and predictability of DH pricing. The DH company and a customer may seek mediation from the DH Board. Customer engagement is critical for DH companies in Sweden, as there are no mandatory connections, and companies rely on good customer relations to grow their market share in the heating market [19,39,44].

Helsinki, Finland

The exploitation of the dominant market position is prohibited, which sets out certain conditions for DH operators, as regards their pricing and cost elements including new capacity investments. Several district heating companies have published terms and pricing structures for the purchase of heat from third party producers. The Finnish Competition and Consumer Authority (FCCA) may initiate investigations if it suspects that prices are being abused by unreasonably high prices, as a result of the dominant market position of district heating [13,21].

Financial Instruments and Incentives

Copenhagen, Denmark

Since 1979, all investments have been 100% financed by competitive loan rates. Funding through affordable loans for DH investments is readily accessible, at estimated interest rates of around 2%. The revolving fund is supplied by the Danish “Kommune Bank” which provides competitive debt financing of long term loans for Danish municipalities, which also finance 100 % of its DH investments through these loans in compliance with municipal guarantees [19,22]. Access to capital is a critical factor in the development of the Danish DH sector. Low interest rates on capital (ca. 2%) enable a financial case to be built even if the rate of return on a network is only 4%. Additionally, there is a public works fund from which municipalities can borrow money to fund DH development [19,22].

Stockholm, Sweden

The first major developments in CHP were introduced in 1991 and mainly supported by subsidies from investment grants programmes that promote the development of efficient electricity and energy technologies, providing around EUR 116 million in the period 1991-1998. Investment grants covering 25% of the investment costs were made available to only CHP biofuels powered plants with a maximum of SEK 4000 / kW (EUR 415 / kW) between 1998 and 2004 [19,22]. Grants for converting heat plants to CHP plants were also available. Currently, DH network development and investment are currently driven by DH companies, rather than municipalities or the central government. The corporative investment, innovation and collaboration among DH companies is perceived as a good outcome of the lack of regulation [19,22].

Helsinki, Finland

DH in Helsinki has always been for profit-driven with a competitive price level. The investments made to improve operations are financed through profits earned in the free DH market in accordance with free competition. In certain instances, investment in renewable heat sources can be financed through investment funding which may be provided by businesses, municipalities and other organisations to small new heating plants powered by renewable energy [13,31,32].

KEY LESSONS

While district heating has the potentials to generate huge carbon savings, it is however a complex system for cities to implement. DH technology merges three functional aspects of the energy system which include: generation, distribution and demand [47,59]. DH could turn out to be a burden for decision-makers and consumers when it is inefficiently operated as they are custom-built technologies that require sound social, technological and economic investigation as well as an effective regulatory framework in order to achieve its aim [36]. Some of the important **key success factors** (KSF) contributing to the large-scale implementation of DH systems in Copenhagen, Stockholm and Helsinki are outlined below [19,22]:

Pricing is one of the primary reasons for the introduction of regulation in Copenhagen as pricing regulation is based on capping DH operator profits. Stockholm and Helsinki operate a liberalised DH market with unregulated pricing, which promotes competition between various heat suppliers. Prisdialogen (Stockholm) and the Finnish Competition and Consumer Authority strengthen the position of customers by promoting fair prices, and predictability of DH pricing in order to prevent exploitation. Inflexible pricing can deter developers from entering the market and upgrade of existing systems. It may also limit innovation and cause domestic customers to abandon the DH network for cheaper alternatives. Full price deregulation, on the other hand, has been criticized for negatively impacting consumer outcomes by weakening customer service and protections.

Transparency is another tenet of most regulatory approaches, though it is achieved in a variety of ways and with varying degrees of success. Transparency strategies must be carefully designed and monitored to ensure that consumers benefit from them. A high degree of transparency through a variety of mandatory and voluntary options (such as publishing of DH prices), have proven to be effective in Copenhagen, Stockholm and Helsinki.

Consumer complaint mechanisms are critical for the effective implementation and regulation of DH, as well as for preventing operators from abusing monopoly positions. Consumer protection standards and satisfaction levels vary according to the degree to which protection is prioritized in regulatory design. Copenhagen (The Energy Supplies Complaint Board), Stockholm (Prisdialogen) and Helsinki (the Finnish Competition and Consumer Authority) appear to have effective complaints procedures in place, which seems to be efficient and of value to consumers.

Technical standards are a critical component of efficient DH network delivery, though their implementation varies (e.g. through licensing or voluntary non-binding standards). However, it must be adaptable so that it does not become a major barrier to innovation and sector development.

In the cities examined, *licensing, zoning, and the award of concessions* are key regulatory mechanisms. These are widely regarded as important and beneficial because they contribute to market stability. However, excessive administration or application rigidity can create barriers for operators.

Mandatory connections in which customers are required to connect to a DH network where one is available can guarantee sufficient heat demand. As Copenhagen has shown, this can be a critical factor in driving investment in DH network development.

Third-party access and the supply of excess heat supply from industries have a high potential to significantly increase market investment. However, many cities have yet to discover a way to fully promote or benefit from the supply of excess heat. While third-party access is prevalent in the cities studied, it can create investment uncertainty for operators. As operators have the right to refuse, and requests can be rejected. It is critical to carefully consider whether and how to “open up” the market.

As demonstrated in Copenhagen, *DH regulation needs to be consistent with national and municipal planning*, as planning-related features such as zoning or mandatory connections can have a significant impact on market development. Also, a clear division of national and local government responsibilities is essential for effective market and sector development. The regulatory regime is inextricably linked to the socioeconomic, infrastructure, and historical characteristics of each city. Effective regulation requires long-term planning, buy-in, and collaboration from both industry and political areas.

Effective regulation requires *broad policy support*. The presence or absence of well-designed subsidy schemes or frameworks that enable developers to access development finance has a significant impact on the development of the DH market. Copenhagen, Stockholm, and Helsinki are examples of successful cities in this regard. Tax incentives and subsidies could also act as a barrier and a limiting factor to stimulating successful DH investment, it is therefore critical to plan and account for the broader socio-economic consequences of such approaches.

CONCLUSION

This study provides lessons learned from the successful implementation of large-scale DH systems in three Scandinavian cities, which can help key actors and policymakers consider how to implement DH and whether and how regulation should be introduced. The implementation strategy differs between the cities studied, and the regulatory model can only be evaluated reliably within the context of each city. Given the emerging nature of their DH sectors and comparable economies, it offers some lessons on the role of DH in decarbonising heat and the transition away from a historical reliance on fossil fuels. Each regulatory model provides both positive and negative lessons that are useful for informing decision makers. The following are the four key success factors of an effective district heating system identified in this research:

- Long-term planning and commitment to DH development
- Successful application of tools that promote market development and investment in the sector
- Coordination of national and municipal governments, as well as the opportunity for industry interests to have a say in certain regulatory issues

These are the most important lessons to consider in the implementation of large-scale district heating systems in order to build capacity in this rapidly emerging industry sector in order to achieve a 50% reduction in carbon emissions by 2030 and net-zero emissions by 2050.

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LIGHT POLLUTION SPATIAL IMPACT ASSESSMENT IN HONG KONG: A CASE STUDY WITH MEASUREMENT AND NUMERICAL MODELLING

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ABSTRACT

Outdoor commercial lighting becomes an icon of urbanization. The excessive use of these commercial lighting causes not only energy wastage, also the light trespass that impacts human health. More than 60% of the sky on earth is covered by light pollution, and about 80% of the world population suffers from its effect. Hence, many jurisdictions demand polices to control the light pollution. Hong Kong, famed as Pearl of the Orient, is one of the most light-affected cities. This study aimed to assess light pollution quantitatively through measurement and numerical modelling. Site measurement protocols were developed and carried out in the busiest area which also received the most complaints on the light nuisance) in Hong Kong. In this study, the illuminance level on the street was measured. In the shopping area, the average vertical illuminance ranged from 44 to 1142 lux, with a mean of 223 lux. In the mixed-use area, a range from 14 to 556 lux and a mean of 130 lux were found. Findings showed illuminance levels are of 2.8-3.7 times (on average) in the shopping area and 1.6-2.2 times in the mixed-use one in excess of the International Commission on Illumination's (CIE) recommended levels (60-80 lux). The measured areas were also modelled with DIALux. This effort complemented the measurements by providing a means to increase the resolution on the light variation and to visualize the light pollution in a 3D environment. This study serves as a pilot study in quantifying light pollution in an urbanized area in order to eventually develop effective pollution management and policy.

KEYWORDS

testing and simulation approach; spatial distribution; urban residential and commercial zones; advertising boards

INTRODUCTION

Light pollution, according to the International Dark-Sky Association (IDA) [1], is the degradation of the environment and human health caused by excessive artificial lighting sources (such as streetlights, neon signs, and illuminated light boards, etc.). Excessive artificial light can lead to consequences such as disruption of ecosystems and organisms, interference with astronomical activities, waste of energy, and negative health impact of people. Any form of outdoor lighting that is obtrusive, misdirected, or excessive, can become a source of pollution. Different components of light pollution have distinct characteristics and impacts; and IDA categorized light pollution into four types: glare, skyglow, light trespass, and clutter. The extent of the artificial night sky brightness for different regions of the world can be found in an atlas [2] prepared by Falchi, et al.

In recent years, the light pollution problem has been quantified through field measurements and modelling works [3,4]. A light pollution assessment study in Beijing was reported [3]. The proposed approach is easy to conduct and with low cost and quick data analysis process. It was showed that the vertical illumination of windows of residential buildings in the area, a commercial-cum-residential area called 'The Place' in Beijing, was in the range from 2 to 23 lux, which is far greater than the recommended CIE values of 11 lux for the window vertical illuminance after curfew. The National Institute of Environmental Research of Korea (NIERK) in Seoul has also developed their prototype measurement for determining light pollution from external sources [4]. The work concluded that vertical luminance values of 67%, 70%, and 86% of the street and security lighting exceeded the recommended values in residential, semi-residential, and industrial areas. Studies on light illuminance have been reported worldwide [5-10] and qualitative assessment have been reported in Hong Kong [11-15]. Figure 1 shows the light distribution in Hong Kong.

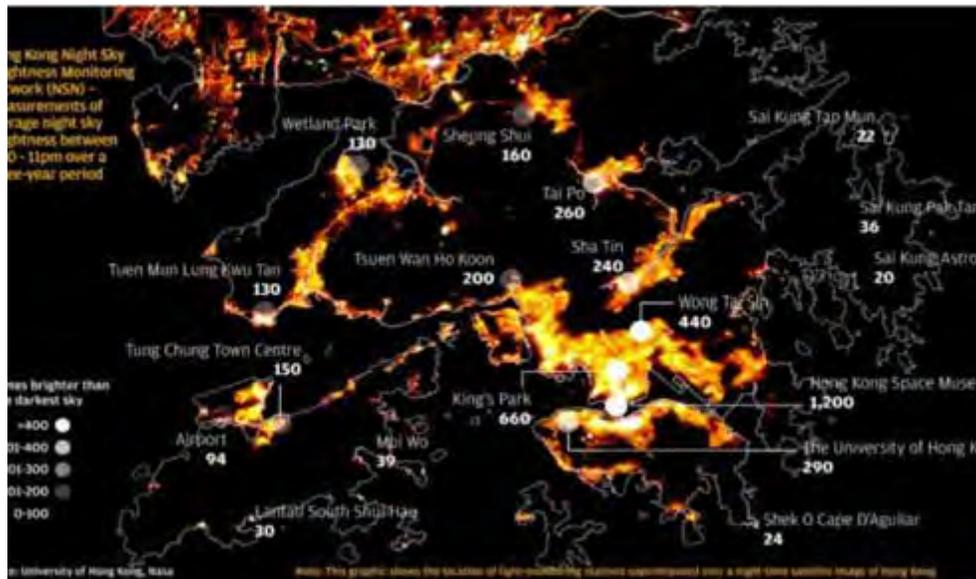


Figure 1. Hong Kong at night as seen from the space shuttle [16]

Light trespass and light clutter are the two components that directly impact Hong Kong's citizens. The study of light trespass to households is on unwanted light where it is not intended or needed; and the study of light clutter focuses on a combination of bright, confusing, and excessive light sources. In this study, Sai Yeung Choi (SYC) Street in Mong Kok ('Shopping area') and Hankow Road and Lock Road in Tsim Sha Tsui ('Mixed-use area') were chosen to be the studied area because these two areas are among the most serious light pollution areas in Hong Kong, and SYC Street exhibited a large range of artificial light sources from neon and flood lights to LED screens. The aim of this study is to quantify the light illuminance on the street level and assess their trespass potential to the areas nearby.

METHODOLOGY

Sai Yeung Choi (SYC) Street is one of the busiest streets in Mong Kok. Light pollution problem is severe there where the dazzling light sources, spotlights and billboards, causes disturbances at night. To balance data sufficiency and measurement efficiency, 70 measurement points were distributed in the study area of SYC Street; and the measurement was taken between 8pm and 10pm. In the same manner, the testing protocol was carried out at the second test site in Tsim Sha Tsui, where 24 measurement points were conducted. As seen in Figure 2, from left to right along the section of the street, the points were aligned in five straight lines referred to as Columns 1 to 5. Columns 1 and 5 are right in front of the stores at the two sides of SYC Street; Columns 2 and 4 are positioned at the rim of the pavement near the road; Column 3 is at the centre of the road. Each sampling point along each of the five columns is separated in an interval of 10 meters. Figure 3 shows the situation in Tsim Sha Tsui where 3 columns were chosen for Hankow Road and Lock Road and eight equal points along each column.

RS Pro's Digital Light Meter ILM 1332A has basic lux meter features such as instant measurement responses and cosine angular correction [17]; and was capable to measure light levels ranging from 0.1 lux to 200,000 lux. During site testing, at each sampling position, the lux meter was held at eye level (1.5 meter above ground) for all measurement, where horizontal illumination was measured from the upward-facing direction and vertical illuminations were measured in the four orientations (reference to the pseudo north, east, south and west, aligned with the street's direction as shown in Figure 1). The vertical illumination measurement is more similar to what a person would experience on the street, while the horizontal illumination measurement can be used to reflect more directly the intensity from the source. Similar to that for the case study in Beijing [3], the average of the vertical illuminance measured from the four directions was taken as the illuminance of the sampling position and was reported for further treatment and analyses.

DIALux is a free and open professional lighting design software and was used for the numerical simulation. 3D spatial models of the neighbourhood were constructed to assess the spatial impact of the light in the studied areas. 3D models with predefined dimensions of the specific districts of Hong Kong were downloaded from the Hong Kong Map Service website; and the models were then further edited with AutoCAD to trim down to our study areas. In the model, all light sources (including residential lights on upper floors, commercial lights on lower floors, streetlights, and spotlights) along the streets were introduced into the model as luminaires in a simplified, standardised, and classified way, either in clusters or individuals. For each cluster, which was defined for each building in the study areas, uniform luminaire is assumed and only the total luminous flux value (lumen level, unit: lm) was calculated (as luminaire luminous flux * the number of luminaires for the cluster). The calculated luminaire luminous flux values were regarded as independent variables. The best-fit model of the correlation between the DIALux simulation results and the in-situ measurement was determined with the Pearson coefficient of determination >0.95.

RESULTS AND DISCUSSION

Over 1100 lux was recorded in Sai Yeung Choi (SYC) Street, with an average of 223 lux (44 to 1142 lux), and over 500 lux was measured with an average of 130 lux (14 to 556 lux) in Hankow Road and Lock Road. The tabulated tables in Figures 2 and 3 show the distribution of the measurements for the two respective locations.

As seen in the table in Figure 2, it is generally brighter near the two sides of the street (Columns 1 and 5) compared with the centre (Column 3); as closer proximity to light sources at the two sides results in higher illuminance. This observation shows that pedestrians are likely to be more affected by light pollution than drivers on the road. In addition, a much larger fluctuation is found in Columns 1 and 5 than the other three columns. This means that the pedestrians, who walk along the sides of the street, will possibly experience discomfort by a drastically changing level of brightness.

Compared with the light pollution case study in Beijing [3], it is found that our site measurements have significantly higher illuminance that ranged from 8 to 315 lux in their studied site. Referencing the recommended average illuminance for pedestrian walkways in urban areas is 60 to 80 lux in the CIE document [18]. It is apparent that the illuminances were significantly higher than the recommended level in SYC Street (2.8-3.7 times), Hankow Road and Lock Road (1.6-2.2 times), and this excessive amount of light causes nuisance in the area.

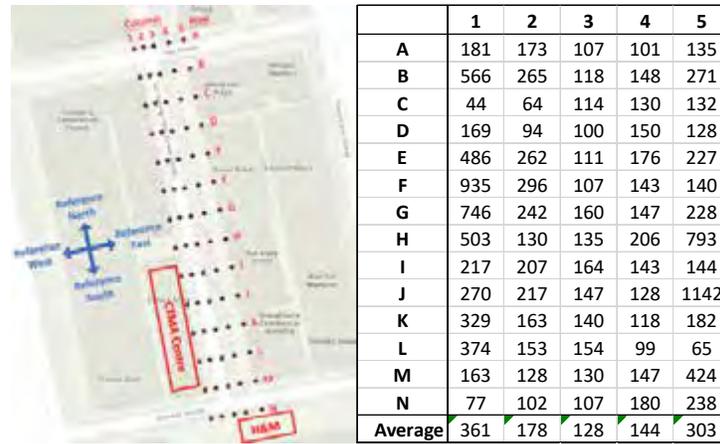


Figure 2. Average of vertical illumination (lux) measurement of 70 points taken in SYC Street, Mong Kok

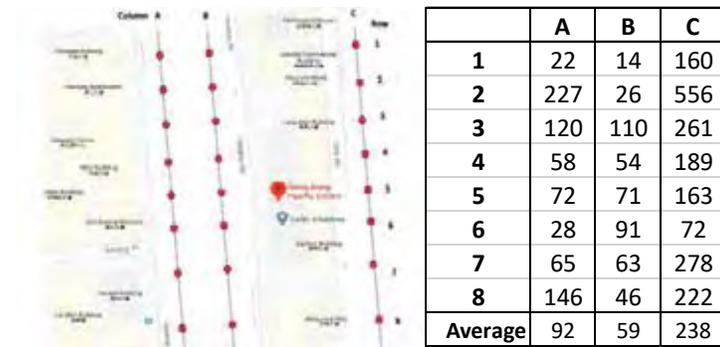


Figure 3. Average of vertical illumination (lux) measurement at 24 points taken in Hankow Road and Lock Road in Tsim Sha Tsui

For getting the best-fit model for Mong Kok area, multiple trials, more than 30, were conducted to raise the R^2 from 0.18 to the desired outcome > 0.95 . For achieving the best-fit model for Tsim Sha Tsui area, total of 208 trials were conducted in DIALux. Among which, 175 trials served for the calibration purpose. The overall R^2 for correlation in the best-fit model is 0.998. For the two horizontal surfaces of Hankow Road and Lock Road, the R^2 were 0.995 and 0.998, respectively. For all calculation objects on four vertical surfaces combined of the studied commercial building, the R^2 was 0.959. From the best-fit model, the hotspots from the simulation generally matched up against the ones from the measurement while the produced luminous values were comparable.

CONCLUSION

Light pollution is unarguably a severe problem in Hong Kong affecting many local citizens. Currently, most actions taken by the Hong Kong government are on a voluntary basis, and there is no quantitative framework available for evaluating the impacts from excessive lightings. Therefore, this study aimed at providing a systematic approach to investigate and evaluate the situation. With the results, an approach adopting both measurement and modelling is recommended for future studies on light pollution for assessment, planning and design on lighting arrangement, and designing a proper standard that can define light pollution quantitatively (which might include level of light intensity, quantity of light source, time and duration, location, etc.) is recommended to carry out by the government.

Based on the measurement analysis of illumination, it is recommended the future studies should use a measurement protocol that includes measuring illumination from all directions and measuring the luminaires' luminance. To balance the accuracy and measurement effort, the proper sampling resolution on the street level should be considered. Furthermore, to capture the effect of light pollution on the vertical level, different vertical heights and at different floors of buildings nearby should be taken.

Light pollution is a complex problem, which requires collaboration from different stakeholders to mitigate the impact. More studies are still needed to further understand the situation and to investigate a feasible framework for assessing impacts of light pollution. Furthermore, community education is essential; and to ensure appropriate public engagement tools are used to highlight the severity of the problem, the understanding of the cultural influence and stakeholders' interests are vital. Nevertheless, for different stakeholders to have a clear guidance to follow, it is hoped that the government could take a leading role to design binding standards for lighting design as a starting point to combat light pollution.

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ACHIEVEMENTS, FLAWS, AND FUTURE GOALS OF SCIENTIFIC RESEARCH ON GREEN ROOFS IN MEDITERRANEAN CITIES: FIRST FEEDBACK FROM ONGOING META-ANALYSIS

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ABSTRACT

Current scientific research points out the low number of papers focused on the environmental patterns in Mediterranean urban areas, where green infrastructure is still strongly underrated by scientists as well as by politicians, planners and decision-makers. In this paper, the results of a simple meta-analysis on the topics treated in scientific literature about the Mediterranean green roofs (MGRs) are presented. Our review pointed out the strikingly higher attention paid to building materials, energy efficiency and hydraulics with respect to life sciences (including basic ecology, horticulture, soil, plant and animal sciences) in the target paper selection. In fact, despite the availability of plentiful information about the Mediterranean vascular flora and vegetation, this is not so informing the selection of plants for roof greening purposes. The role of soil-based substrates in local bio-geochemical cycles, plant and animal communities and their dynamics have also been poorly studied so far. Social and perceptive aspects are completely underrated too, whilst the management strategies and the dominant economic approach are informed more by energy-saving than by the finding innovative and sustainable materials and techniques. More investments are needed to: 1) diversify the techniques and materials for roof construction, respecting local ecoregional features and circular economy; 2) sustain the use of native plants, well adapted to stand environmental stress and anthropogenic disturbance; 3) avoid potentially invasive alien plants; 4) implement the cost-benefit effectiveness of MGRs in the medium- and long-term.

KEYWORDS

literature review; semi-arid habitats; urban ecosystems; Mediterranean Basin

INTRODUCTION

Although the oldest cities of Europe were built in the Mediterranean Basin, and some of them (e.g., Athens, Alexandria, Syracuse, Rome, Istanbul) have been very large and densely populated since antiquity and for long time, little attention has been paid to these in terms of urban ecology.

After 1960s the Mediterranean Basin has experienced the same socioeconomic and demographic processes that affected people worldwide [1]. The economic decline of agropastoral practices induced people to abandon inland areas and migrate toward the cities – mostly concentrated near the main rivers and the coasts – looking for new job opportunities (e.g., industry, tourism). Following this trend, Mediterranean cities (henceforth MCs) are experiencing ever increasing built (sealed) surface areas, resource consumption, carbon footprint and number of inhabitants [2]. In fact, 13 of them (mostly concentrated in North Africa and the Near East) host more than one million inhabitants, and the population of some more 40 cities exceeds 250,000 units (<http://mc3.lped.fr/Les-caracteristiques-des-villes-Mediterraneennes?lang=en>). As a result, many MCs are currently facing a dramatic social and ecological crisis, not only the largest and the medium-sized ones, but also the small ones are too densely inhabited (e.g., Valletta) or completely deprived of natural and semi-natural areas (e.g., Beirut), appearing just ‘hostile’ to their inhabitants basing on a wide spectrum of indicators (e.g., air quality, noise, green space/inhabitant).

In such an alarming scenario, it appears crucial to find out ways to improve the quality of urban spaces and to invert the above-mentioned landscape degradation/habitat fragmentation trend. The best option to make MCs more liveable places is to ‘revive’ local natural heritage, for instance by raising the citizens’ awareness of the value of local landmarks, by protecting and restoring the remnant patches of urban soils and ecosystems, enhancing their connectivity (e.g., watershed, food webs, ecological corridors, steppingstones) to ‘re-start’ natural processes. In this framework, the set-up of green roofs represents an effective strategy to improve the overall surface, structure and functionality of urban green infrastructure, a tool that has been overlooked by city planners, landscape architects, urban ecologists, and decision makers in the Mediterranean context [3].

This paper aims at providing a synthetic, yet preliminary view of the main results of the scientific research on Mediterranean green roofs (henceforth MGRs) and drafting the knowledge gaps and the questions which are still waiting to be experimentally addressed and answered. While some robust bibliometric studies already exist focusing on green roofs worldwide [4, 5] we found that the number of publications in this field increased in the last two decades at very similar pace to other pre-established academic disciplines. We also found that papers on green roofs were classified into 32 research areas. There was very little change in the frequency of most research areas through time. The percentages of plant sciences, forestry, marine and freshwater biology and biodiversity conservation of the total research areas classifications used each year increased significantly with time, while architecture decreased significantly with time signifying an increased interest in environmental issues and less focus on architectural issues. The distribution of publications between countries has been skewed, with the USA and the EU conducting 66% of the research, and thus allocation of research effort is focused in those continents and predominantly in temperate ecosystems. However, there has been a sharp increase in the number of countries that conduct green roof research. Our work provides a suite of indicators that can be combined to give a useful picture of the development of green roof research and identifies the challenges which lie ahead for this novel research area. (C, to the best of our knowledge, no previous research has identified and provided meta-analysis of the review on MGRs research in MCs.

MATERIAL & METHODS

This review is based on a study of papers about MGRs, retrieved peer-reviewed journals. A simple query was carried out by selecting in the Web of Science (WoS, last accessed: December 27, 2021) the peer-reviewed articles obtained by the search keys “green roof*”, with and without “Mediterranean”, in the topic field (i.e., searching in title, abstract and keywords). These were named “MED” and “NOT MED”, respectively:

1. MED: TS=(“green roof*”) and TS=(Mediterranean) and Articles (Document Types) (<https://www.webofscience.com/wos/woscc/summary/90b497f3-b1ce-4d09-b45c-4efe78ddea37-1d4073f3/times-cited-descending/1>)
2. NOT MED: TS=(“green roof*”) NOT TS=(Mediterranean) and Articles (Document Types) (<https://www.webofscience.com/wos/woscc/summary/35b9a6a8-8957-47f9-9f1b-d3d3ab85f015-1ef82312/times-cited-descending/1>)

Additionally, we created and analysed the subset ‘NOT MED (MED BASIN)’ to have an idea of the number of articles included in the ‘NOT MED’ dataset which indeed are focused on MGRs.

3. NOT MED (MED BASIN): TS=(“green roof*”) NOT TS=(Mediterranean) and Articles (Document Types) and Articles or Early Access (Document Types) and ITALY or FRANCE or SPAIN or GREECE or TURKEY or EGYPT or ISRAEL or CYPRUS or SLOVENIA or LEBANON or ALGERIA or CROATIA or BOSNIA HERCEG (Countries/Regions) (<https://www.webofscience.com/wos/woscc/summary/257267b8-7a81-407a-801a-690c45ab19bd-1ef82068/times-cited-descending/1>).

To obtain a deeper insight on the focus of the ‘MED’ papers, we searched for several dozens of topics included (or not included) in the title, the key words and/or the abstract of our paper selection. These topics have been grouped as follows:

1. Technical Approaches & Building Materials (e.g., ‘Building’, ‘Design’, ‘Construct*’, ‘Material’),
2. Energy, Water & Climate (e.g., ‘Energ*’, ‘Climat*’, ‘Drainage’, ‘Runoff’, ‘Hydrol*’, ‘Heat’),
3. Ecology, Biogeography & Conservation (e.g., ‘Community’, ‘Ecosyst*’, ‘Native’, ‘Disturbance’),
4. Soil Sciences & Agriculture/Horticulture (e.g., ‘Substrate’, Nitrogen’, ‘Soil Microorg*’),
5. Plant Sciences (e.g., ‘Physiology’, ‘Vegetation’, ‘Metabolism’, ‘Life Form’),
6. Animal Sciences (e.g., ‘Arthropod’, ‘Insect’, ‘Vertebrate’, ‘Bird’),
7. Social Sciences & Psychology (e.g., ‘Well-Being’, ‘Recreat*’, ‘Awareness’),
8. Management Strategies & Economy (e.g., ‘Cost-Benefit’, ‘Sustainab*’, ‘Management’).

RESULTS

The global scale

The first automatic query carried out on the Web of Science for “green roof*” NOT “Mediterranean” in title, abstract, keywords (authors’ keywords and keywords plus) yielded 1928 ‘NOT MED’ papers published during last 25 years (1996-2021, Fig. 1), Wolch et al. [6] being the most cited (1351 citations) and Kralli et al. [7] the oldest work. According to the Web of Science categories, more than 70% of these papers belong to three main categories (Fig. 2), i.e., Environmental Sciences (731 items, 37.1%), Civil Engineering (361 items, 18.3%), Environmental Engineering (340 items, 17,3%). Most of these studies were carried out in USA, Europe and China (Fig. 3).

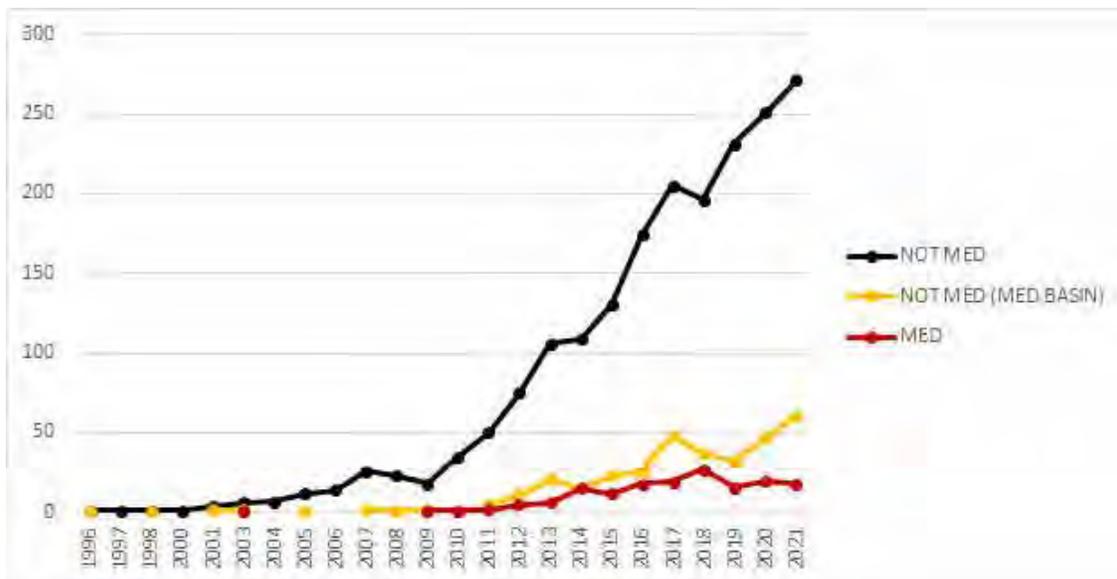


Figure 1. Diachronic comparison of the yearly publications of NOT MED (incl. NOT MED - MED BASIN) vs. MED papers.

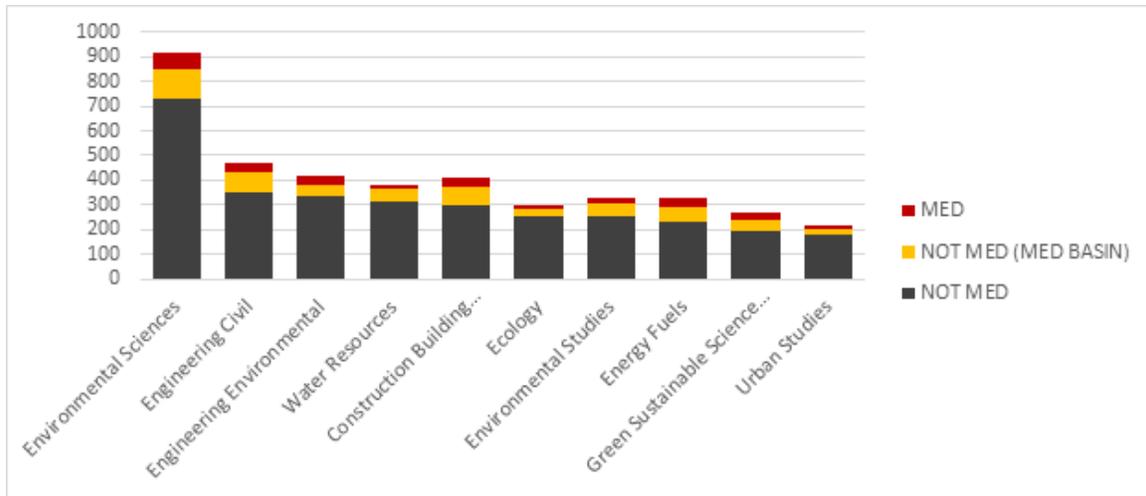


Figure 2. Top 10 categories (according to WoS classification scheme) of the NOT MED (incl. NOT MED - MED BASIN) vs. MED papers.



Figure 3. Geographical distribution and number of the NOT MED papers; only the most scientifically productive countries are mentioned. The Mediterranean countries of Europe, Asia and Africa (MED EUROPE, MED ASIA and MED AFRICA) are pointed out.

The second automatic query on the Web of Science for “green roof*” and “Mediterranean” title, abstract, keywords yielded 161 ‘MED’ articles (Fig. 4) published in the last 19 years (2003-2021), with Zinzi and Angoli [8] as well as the intensification of the urban heat island effect. This trend is observed at several latitudes, including areas where overheating was unknown at building and urban levels. This phenomenon involves different issues: reduction of greenhouse gases, quality and comfort in outdoor and indoor environment, security of energy supply, public health. The building sector is directly involved in this change and adequate solutions can provide great benefit at energy and environmental levels. Roofs in particular are envelope components for which advanced solutions can provide significant energy savings in cooled buildings or improve indoor thermal conditions in not cooled buildings. Cool materials keep the roof cool under the sun by reflecting the incident solar radiation away from the building and radiating the heat away at night. Roofs covered with vegetation take benefits of the additional thermal insulation

provided by the soil and of the evapo-transpiration to keep the roof cool under the sun. These two technologies are different in: structural requirements, initial and lifetime maintenance costs, impact on the overall energy performance of buildings. This paper presents a numerical comparative analysis between these solutions, taking into account the several parameters that affect the final energy performances. By means of dynamic simulations, the paper depicts how cool and green roofs can improve the energy performance of residential buildings in different localities at Mediterranean latitudes. (C being the most cited (N=250) and Theodosiou [9] the oldest work, with 162 citations.

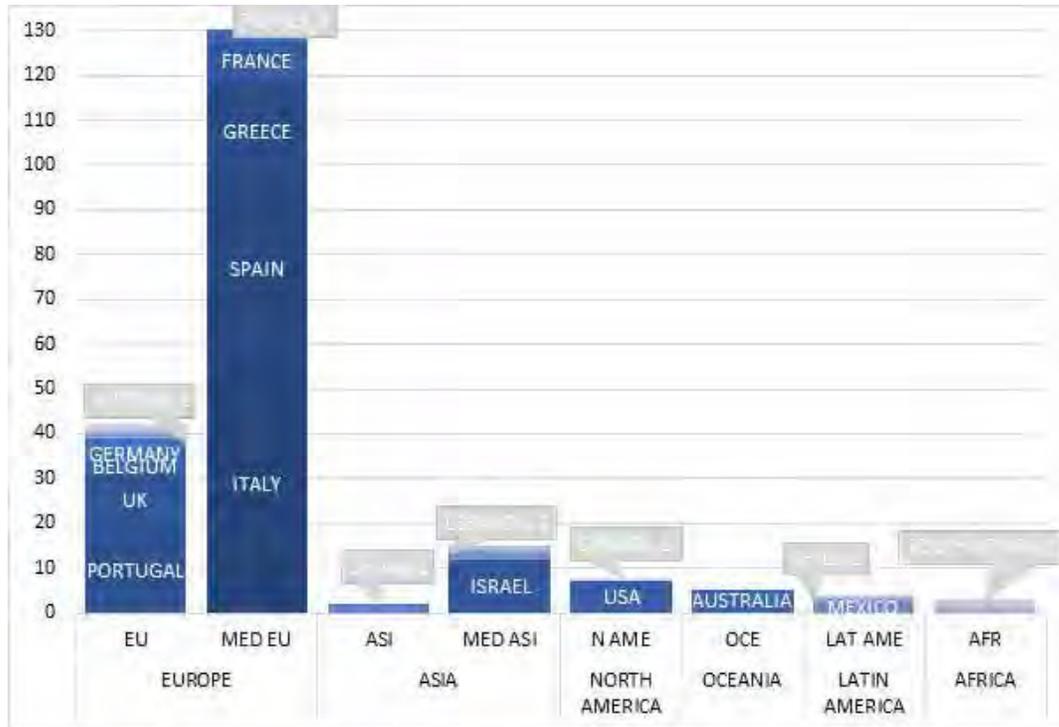


Figure 4. Geographical distribution and number of the MED papers; only the most scientifically productive countries are mentioned. The Mediterranean countries of Europe, Asia and Africa (MED EUROPE, MED ASIA and MED AFRICA) are pointed out.

The Mediterranean scale

Figure 5 illustrates the frequency of the words whose occurrence was checked throughout the MED paper selection.

As for the topic ‘Technical Approaches & Building Materials’ the word ‘Building’ is among the most cited ones, featuring 89 times, followed by ‘Design’ (N=49), ‘Construct*’ (N=31), ‘Material’ (N=29) and ‘Techni*’ (N=22). Much more attention seems to be paid to the different types of material (e.g., ‘Concrete’, ‘Geotextiles’, ‘Rubber Crumb’) used to build MGRs than on other important issues such as ‘Engineering’ options (N=4).

The term ‘Energy’ is featured 83 times, whilst the words ‘Performance’ and ‘Efficiency’ appear on 110 and 42 papers, respectively, their use being mostly referred, once again, to energy. Other frequently occurring words are ‘Insulat*’ (N=34), ‘Energy Consumption’ (N=28), ‘Coating’ (N=6). With 89 citations, ‘Water’ features among the most important factors taken into consideration. Other frequently cited terms related with water are ‘Irrigation’ (N=46), ‘Runoff’ (N=36), ‘Drought’ (N=34), ‘Drainage’ (N=26), ‘Arid’ (N=23), ‘Stormwater’ (N=21), ‘Hydrol*’ and ‘Moisture’ (N=20), ‘Hydraul*’ (N=18). Strikingly less attention is paid to ‘Water use/retention/storage’ (N=14) and ‘Water availability’ (N=10).

With 111 occurrences, ‘Climat*’ is among the most cited words within the title, keywords and abstract of the selected papers. Other correlated and frequently mentioned terms are ‘Heat’ (N=66), ‘Thermal’ (N=63), ‘Temperature’ (N=48), ‘Cooling’ (N=41), ‘Winter’ (N=28), ‘Heat Island’ (N=24), ‘Climate Change’ (N=20), ‘Thermal Insulation’ (N=15), ‘Thermal Comfort’ (N=13). Very few papers mention and consider the two other yearly seasons, i.e., ‘Spring’ (N=8) and ‘Autumn’ (N=5), or other local climatic factors such as ‘Wind’ (N=6) and light conditions: for instance, ‘Shad*’ is mentioned only 6 times and ‘Albedo’ only 4.

Surprisingly enough, economic aspects do not seem to be a focus of the studies concerning MGRs. Among the most cited terms dealing with this topic, the most cited resulted to be ‘Econ*’ (N= 36 times, i.e., only 22% of the whole paper selection) and ‘Management’ (N=33). However, both these terms, as well as many other strictly linked with economy, like ‘Sustainab*’ (N=51), ‘Cost’ (N=29), ‘Energy saving’ (N=28), ‘Effective’ (N=21), mostly refer to the initial construction costs, while the medium- and long-term perspective is somehow missing, as shown by the fact that each of the terms ‘Cost-effective’, ‘Cost-benefit’ and ‘Recycl*’ is mentioned roughly 10 times in our dataset. Although the term ‘Monitor*’ is quoted 31 times, the paper selection appears to ‘hide’ the need of regular and often expensive interventions during the whole green roof life-cycle; in fact, the term ‘Removal’ features only on 6 papers, ‘Weed’ only once and ‘Eradication’ never.

DISCUSSION

The datasets ‘NOT MED’ and ‘MED’ obtained automatically by querying the WoS turned to be partially biased. In fact, on the one hand many authors did not specify the biome where their study was carried out (e.g., ‘temperate’, ‘Mediterranean’) in the query field (title, keywords and abstract); on the other hand, the keyword ‘Mediterranean’ featured in papers illustrating non-Mediterranean study cases (e.g., inner USA, China, Portugal). A deeper insight on the subset NOT MED (MED BASIN) could only partially solve the first issue. In fact, several investigations done by researchers working in Mediterranean countries were focused on extra-Mediterranean territories (e.g., French scientists presenting study cases from Northern France or central Africa).

Most of the papers of the MED selection were focused on technical features and aim at optimizing energy consumption. In most of the selected papers improving green roof performance means just obtaining optimal thermal insulation, look for the best option to mitigate urban climatic conditions, namely heat waves in summer and excessive thermal dispersion during winter. Remarkably enough, very few papers considered spring and autumn, the two most important seasons for Mediterranean plant life cycles.

Water management is among the main topics, too. On the one hand, much of the selected works dealing with this topic are only focused on the most suitable materials and techniques to be adopted to improve drainage and/or avoid risks and damages due to extreme events. On the other hand, very few efforts have been made to inform the choice of MGR materials and living components to local climatic conditions.

Unable to get rid of the ‘temperate archetype’, many professionals are still convinced that the MGRs should be ‘green’ also in summer, and as many as 46 (28.5%) of the selected papers invoke ‘Irrigation’ as the best solution against the seasonal water shortage affecting the plants growing on MGRs. This idea is an unsustainable nonsense in the Mediterranean context, whose plant communities should instead be able to grow, spread and reproduce without any external water supply. To do that, designers should find out the best solutions to exploit local microclimatic conditions, for instance to capture overnight dew, an important water resource in Mediterranean coastal cities, and professionals should invest more in applied research on the making of uneven and patchy green roofs, hosting near-natural and self-sustaining Mediterranean habitats like winter-green annual swards, temporary ponds, etc.

The rather high frequency of the term ‘Native’ (featuring on more than 20% of the papers of our selection) suggests an increasing awareness of professionals about biogeographic features in the making of MGRs.

If left free to evolve following natural succession processes, plant communities growing on green roofs will form patches differing in terms of structure, species composition, functional spectrum, thus enhancing urban biodiversity [11–14] particularly through the planning and management of urban green spaces (UGS). In this way, MGRs may provide key-spaces and key-opportunities to mitigate and compensate human impact due to urban sprawl [15], and may represent key steppingstones and functional ecological corridors enhancing the dispersal and spread of plants, animals and habitats [16] and they offer promising additional opportunities to enhance biodiversity in cities. However, their ecological conditions remain poorly considered when planning wildlife corridors. To discuss the role of vegetated buildings in landscape connectivity, we reviewed the ecological and technical specificities of green walls and green roofs in light of the key factors concerning urban wildlife (patch size, quality, abundance, and isolation).

As far as soil science and agriculture are concerned, most of the current scientific research on MGRs is ruled - and biased - by the hegemony of the few existing companies promoting their commercial and standard substrates, yet fulfilling the most influential German guidelines [17]. Consequently, most of the papers concerning these topics are still focused on the abiotic (physical and chemical) properties of few standard substrates and layering-options, while little effort has been made to develop innovative techniques to better exploit the potential of soil organisms and plant communities to reduce soil pollution. For the same reasons, few resources have been invested to test new materials like volcanic ashes, that accumulate naturally on the roofs in the proximity of the Mediterranean active volcanoes, or to study the biogeochemical cycles of urban (landfill) soils and , or to develop innovative techniques inspired by the habitat template [18], like combining hay transfer [19] and soil transfer [20] to exploit local seedbank and microbiota at the same time.

Concerning plant sciences, only seldom plant selection is informed to nature- or expert-based criteria, and semi-automatised species lists are rare and even more rarely inspired by rigorous biogeographic and ecological criteria [21]. Being tested and used since decades by central-and north-European experts, Stonecrops (genus *Sedum*) are by far the most cited plants used in MGRs, featuring in topics of 23 papers. However, if the aim is to imitate and replicate the Mediterranean habitats, then the best suited plants for the extensive MGRs are not only those being able to face long-lasting drought periods (e.g., geophytes, hemicryptophytes and succulent chamaephytes), but also those adapted to avoid the harshest conditions., i.e. the short-lived therophytes whose life cycle ends up before the dry season begins [22], often underrated or even neglected in the already available plant lists for MGRs [e.g., 23]. As some of these species are rare, endangered and/or linked to conservation priority habitats, their use on MGRs may represent a possible strategy to ameliorate their conservation status. However, very poor experimental data are available on the ecology and biology of many annual plants during the first phases of their life cycle (e.g., germination and establishment). Hence, we cannot be sure that rare or endangered therophytes can be used for green roofs, as some of them may depend on still unknown microbiotic or microclimatic conditions.

Only few papers dealing with MGRs clearly correlate the generic term ‘Vegetation’ with ‘real’ and ‘local’ plant communities. The level of knowledge on the structure, the composition and the natural dynamics of plant communities growing on MGRs appears unsatisfactory. As far as we know, very few vegetation surveys on primary succession on MGRs have been done so far, and none has been published yet.

Moreover, many plants typical of the stress-tolerant Mediterranean vegetation units listed by Mucina et al. [24] could be successfully used on extensive MGRs with low to no management cost. Even better, as these vegetation units often correspond to Habitats identified by Annex I of the 92/43 EEC Directive as European conservation targets, their adoption as habitat templates on extensive MGRs may represent a powerful tool to 1) meet mitigation and compensation measures to contrast habitat fragmentation and disruption loss within and near construction sites, 2) restore habitats of high naturalistic interest and increase their connectivity, 3) reinforce the populations of rare/endangered taxa linked to Mediterranean xeric plant communities.

The term ‘Plant selection’ was recorded only five times. This result confirms that the criteria driving species selection and assemblage are still pretty much confused, and more efforts are needed to better fit species selection to local climate (e.g., drought duration) and to substrate traits (e.g., depth, texture, layering, pH, pollution, nutrient and salt content). Additionally, more attention should be paid to avoid the accidental or deliberate introduction of stress- and disturbance-tolerant, invasive, habitat-shaping alien plants. On the contrary, many papers claiming to adopt “sustainable” plant selection criteria suggest using few cosmopolitan alien plants which are well-known for their invasive behaviour worldwide such as *Carpobrotus* spp., *Paspalum vaginatum*, *Sedum spurium* and *Gaura lindheimeri*.

Our preliminary data analysis pointed out the very low attention paid to the faunistic component of MGRs. Knowledge on this topic needs strong improvement following good examples from central-European green roofs [e.g., 25] among other services, habitat for plants and animals, and stepping stones for mobile organisms, thereby enhancing permeability among habitat patches across densely built cities. In Switzerland, investigations over the past 20 years on more than one hundred distinct green roofs across six cities have provided an unprecedented dataset on ground beetles, albeit with information that is scattered across unpublished reports and local databases. We present here for the first time a synthesis of the state of knowledge of ground beetle communities from green roofs in Switzerland. We describe 91 ground beetle species (19,428 individuals and exploiting the huge amount of data concerning several taxonomic groups living in the Mediterranean cities [e.g., 26].

The number of studies focused on the possible connections between biodiversity, wilderness and citizens' perception of beauty and well-being is steadily increasing worldwide [27, 28] it is important to understand public perceptions of urban green spaces (UGSs). Yet, this topic appears poorly explored in the Mediterranean context, where semi-natural habitats like extensive MGRs may look 'yellow' for many months, and consequently are considered as 'untidy' and undesirable by many people [29] and floristic assemblage was consistent with the regional species pool. No significant levels of biotic homogenization were found. Local activists successfully campaigned to save the site from development, which resulted in its designation as an Urban Nature Reserve; however, it was essentially managed as a conventional neighbourhood park. As a consequence, vascular plant species richness decreased by 50%. The functional and biogeographic groups most typical of Mediterranean habitats saw the largest decrease (the steno-Mediterranean element decreased by 80%).

Only few papers pay attention to the need of regular interventions to manage the plants growing on MGRs, for instance emphasizing the impact of mowing regime on MGRs flower species diversity [30] the biodiversity dynamics during the two-years experiment, and the pollinating fauna, were analysed. Each plant group was able to efficiently colonize the surface of the roof though in different periods and with various modalities. Thermal insulation of green roof was connected to different development dynamics of leaf canopies. In particular, this cooling effect took place during the peak of the vegetation's growth pattern. As expected, each plant group had differing flowering periods, during which were observed coincided highest rate of pollinator' visits (domestic and solitary bees, bumblebees, lepidoptera, diptera both syrphidae and bombyliidae. Similarly, not so much research deals with building costs also due to the lack of built examples. Nevertheless, the feasibility to build (simple intensive) MGRs was investigated with reassuring results [31].

Very few papers consider the medium- and long-term rentability of the applied techniques and of the used (non-living and living) materials. Consequently, the striking unbalance between the frequency of the terms 'Experiment*' and 'Innovation' (69 vs. 10 in the 'MED' paper selection) is not surprising, yet we need to reverse it.

CONCLUSIONS

There is a clear need to establish a science-policy interface, involving soil and vegetation scientists, landscape architects and engineers, to implement and share best practices and collated knowledge on MGRs design and management [32]. Similarly, a traits-based framework from scientific studies to practical application should be encouraged. Here we refer not only to the vegetation functional traits, which differ between the Mediterranean and the temperate ecoregion, but also to the social-ecological traits of the urban environment, e.g., features of humans and other co-inhabiting species and their differing responses to local environmental pressures and drivers.

Despite ecological research on GRs is most advanced in the temperate ecoregions, its techniques and results cannot be taken for granted in the Mediterranean. Experimentation and adequate communication of the results are necessary so that, for example, the summer yellowing of Mediterranean vegetation is accepted unconditionally by the individual and collective perceptions of MGRs. This will support the development of a scientifically grounded, practically applicable framework to interrogate reciprocal feedback linkages, nature-human relationships and decision-making [33] we explore the potential of a traits framework for understanding social-ecological patterns, dynamics, interactions, and tipping points in complex urban systems. To do so, we discuss what kind of framing, and what research, that would allow traits to (1.

This paper represents a first trial to show some common traits and trends in the scientific literature focused on MGRs. To further check any appreciable shift of paradigm from the "construction materials + energetic efficiency + water runoff management" mainstream approach to a more holistic perspective, data should be analysed also from the diachronic perspective, through the lens of soil and vegetation scientists. This could help to verify if and to which extent professionals who build green roofs in the Mediterranean cities started to consider other factors, such as the increasing awareness of citizens about nature as a value *per se*, the physiology of living organisms, the natural dynamics and the functional complexity of the communities they build, the endurance of the materials used, the sustainability of the techniques adopted.

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ECONOMIC FEASIBILITY OF ELECTRICAL BATTERIES FOR NZEB ROW HOUSES IN THE NETHERLANDS

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ABSTRACT

The total amount of renewable energy produced by a net zero energy building is equal or greater to the total amount of energy used on an annual basis. Net zero energy buildings rely on the energy grid to overcome the mismatch between energy production and energy use load patterns. In the Netherlands, this mismatch has currently no negative economic consequences, as there is a net metering agreement. However, this agreement has a close end date, end of 2022, what could make residential energy production and net zero energy buildings less attractive. The addition of a battery storage system to net zero energy buildings could allow to increase the percentage of renewable energy production self-consumption and therefore reduce the possible future energy costs. The aim of this research is to compare three possible future scenarios: (1) with a decreasing net metering agreement, (2) with no net metering agreement and (3) with no net metering agreement and variable wholesale energy market prices. The Matlab/Simulink model used to compare the scenarios has been fed with PV-meter data and smart-meter data of 17 net zero energy row houses located in the Netherlands. The model simulates an ideal battery with no losses. The results shows that with a decreasing net metering agreement, to add a battery will not be economically interesting until the year 2026, but in the case of stopping with the net metering agreement at once it will be immediately profitable and it will have a pay back-time of 7 years. In the case of no net metering agreement and variable wholesale electricity prices a battery will save some energy costs but without a battery charge and discharge control system the pay-back time would be too long to make it economically interesting, at least with the electricity prices of 2019.

KEYWORDS

battery, nzeb, battery sizing, metering agreement, solar, PV system

INTRODUCTION

The goal of the Paris Agreement of 2015 is to keep the rise in global average temperature well below 2 degrees Celsius compared to pre-industrial levels by drastically reducing the emission of greenhouse gases. To reduce the emission of greenhouse gases, the world should stop burning fossil fuels. In the residential building sector this implies a switch from fossil fuel based heating systems to other heating systems such as heat pumps. This change therefore implies an increase on the demand for electric energy. To reduce the electric energy demand associated to the use of heat pumps and to increase the capacity of local renewable energy production the Dutch government has developed multiple programs to promote the increase of building insulation and the installation of PV-systems. The highest level of implementation of this strategy in the residential building sector is the new construction and renovation to net zero energy building (NZEB) level. A NZEB produces as much renewable energy as it consumes over the course of a year.

To further encourage households to use PV-systems the Dutch government introduced the net metering agreement in 2004. With this metering agreement households can deliver energy into the grid. For pricing the amount of energy that is taken from the grid will be subtracted from the energy that is delivered to the grid at the end of the year. If there is a surplus of delivered energy to the grid this will be sold at a fix consumer electricity market price of €0.07/kWh [1]. If there is a surplus of taken energy from the grid the household has to pay at a fix consumer electricity market price of €0.22/kWh [1]. The problem with this agreement is that a certain amount of produced energy that is delivered to the grid is sold at the same price that it is bought. The difference is around €0.15 and it is paid by the government. Because of the high increase of PV- systems installed this incentive is becoming very costly for the Dutch government. Because of the price of this incentive, it is decided to change the metering agreement in 2023 [5]. This will have consequences for the energy bill of residential buildings that deliver renewable energy to the net. Specially for the NZEB.

To counter this negative financial effect, a solution to minimize energy import and maximize self-consumption of produced energy is desirable. This can be done by adding a battery to the system. The energy that is produced by the PV- system which cannot be consumed by the load demand of the household would normally be delivered to the grid. With a battery some of this energy can be stored. Later on when the household demands energy again, the energy that was stored by the battery can be used to meet this demand. The aim of this paper is to determine whether it is beneficial to add a battery to a NZEB. This will be done by comparing the economic performance of the battery on three different scenarios:

1. With a decreasing net metering agreement (as is the current government proposal).
2. Without net metering agreement and fix electricity market prices.
3. Without net metering agreement and variable wholesale electricity market prices.

In the following section there is a description of the model, after that the results of the three scenarios simulations are presented and the paper ends with a discussion of the main findings of this research.

METHOD

The NZEB energy system generates electrical energy with a rooftop PV-system, the energy system is also connected to the electricity grid. In case the PV-system does not deliver enough power it is taken from the grid, and in case of surplus of power this is delivered to the grid. A diagram of this system can be seen in Fig. 1.

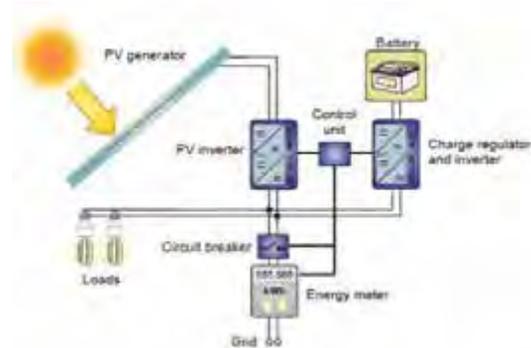


Figure 1. Schematic of energy system of NZEB

The data used in the model has been acquired from a group of 17 net zero energy row houses in Zoetermeer, the Netherlands. All the houses are from the same type, the only difference is that end of the row houses are equipped with a few more solar panels than in between houses. On average the yearly energy production is of 7551 kWh and the energy use of 5129 kWh. The houses are therefore energy positive. The average self-used energy production is of 1661,22 kWh. The average hourly energy import-export profile is presented in Figure 2.

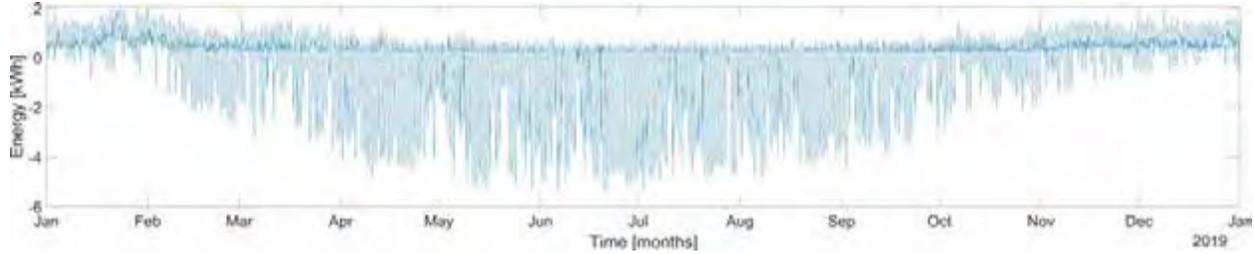


Figure 2: Mean energy balance of group NZEB houses

The data-set used in these paper contains information of energy generated by the rooftop PV-system [kWh] and smart meter import and export [kWh] at a five minute resolution of 17 households. All data used in this paper was recorded in 2019. The data has been reshaped to one hour resolution because variety in time-steps of the smart meter and PV-system meters. Although the mean of the time-steps was at a five minute resolution, the maximum variation between two time-steps was one hour and twenty minutes. Also the time-steps of various meters were not synchronized, reshaping the data made it easier to compare the data between houses. Reshaping was performed using the re-time nearest function of MATLAB.

To analyze the performance of the energy system a model has been created with Matlab/Simulink, in the following section there is a description of the model used.

Battery model description

In this model it is assumed that efficiency of PV inverter, charge regulator and inverter are 100%. It is also assumed that an ideal battery is in place, where there is no energy lost over time and it can deliver or take as much power as needed. This analysis does take the size of capacity of the battery into account.

Every household has its own smart meter which registers the energy that is taken from the grid E_{imp} and the energy that is delivered to the grid E_{exp} . The energy produced by the PV solar system is registered by the PV inverter meter E_{gen} . With the use of Eq. 1 and Eq. 2 is it possible to calculate the household energy use E_{load} and the energy directly used from the PV solar system E_{edu} .

$$E_{imp} = E_{load} - E_{du} \quad [\text{kWh}] \quad (\text{Eq. 1})$$

$$E_{exp} = E_{gen} - E_{du} \quad [\text{kWh}] \quad (\text{Eq. 2})$$

The power is derived from the hourly energy measurements. The power shortage P_{short} (Eq. 3) and the power surplus P_{surpl} (Eq. 4) determines if the battery is charging or delivering energy to the household. If there is a momentary power surplus the power is delivered to the battery. If the maximum capacity of the battery is not reached the battery charges until the battery is fully charged. If there still a surplus after the battery is fully charged the power is delivered to the grid. If there is a momentary power shortage the power will be taken from the battery. If the battery is depleted, the power is taken from the grid.

$$P_{short} = (P_{gen} - P_{load}) < 0 \quad [\text{kW}] \quad (\text{Eq. 3})$$

$$P_{surpl} = (P_{gen} - P_{load}) > 0 \quad [\text{kW}] \quad (\text{Eq. 4})$$

The capacity of the battery have been defined by looking to maximize the savings by adding a battery on scenario 2, without metering agreement. The optimal battery capacity in this scenario and with the battery cost calculation defined in the following section is of 8 kWh. Fig. 2.

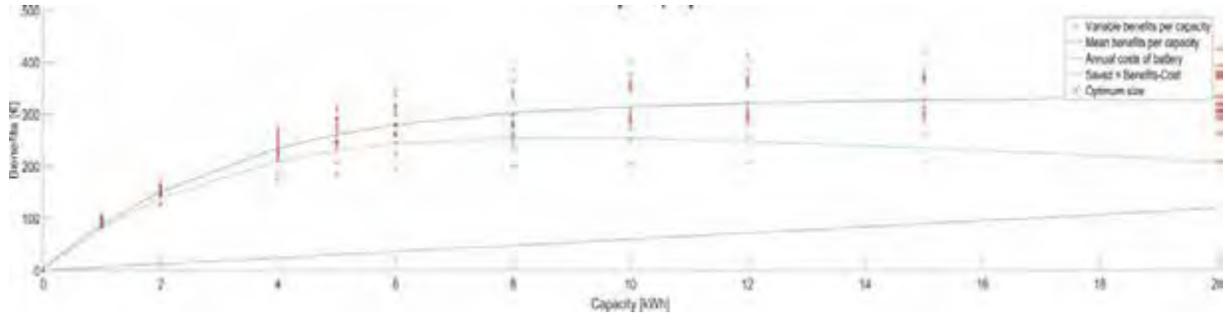


Figure 2: Savings and costs related to different battery sizes

Cost calculation

The parameters used to calculate the costs are presented in Table I, the same parameters have been used as in the research of Maik Naumann [3]. The battery investment costs \$/kWh used are from the blog of renewable energy of the world [4], the price has been recalculated to euros. The variables used in this model are:

Table I: Cost calculation values

| Parameter | Value |
|------------------------------------|-----------------------------------|
| Lifetime battery | 20 years |
| Investment cost battery | €122,71 * Capacity of battery |
| Maintenance cost battery | 1.5% * investment cost every year |
| Installation rate | 5.0% * investment cost |
| Consumer electricity buying price | 0.22 €/kWh |
| Consumer electricity selling price | 0.07 €/kWh |

The wholesale variable energy prices that have been used in scenario three have been collected from the website ENTSO-E Transparency Platform [7]. The prices are different each hour and are defined one day ahead. The prices used for the simulation are from the year 2019, the same year as the energy measurements from the households. In the year 2019 the electricity prices ranged from negative €9 per MWh to positive €120 per MWh with an average of positive €40 per MWh.

The payback time t_{pb} has been calculated taking into account the total investment cost of the battery C_{inv} , the yearly energy cost savings S_{yBat} and the yearly maintenance costs C_m , Eq. 5. The total investment cost C_{inv} has been calculated taking into account the yearly investment cost C_{yInv} , the lifetime of the battery t_{bat} and the installations costs C_{inst} , Eq. 6. The yearly cost savings S_{yBat} has been calculated taking into account the energy discharged from the battery E_{dBat} , the grid energy buying price C_{gp} , the yearly maintenance cost C_m and the yearly investment cost C_{yInv} , Eq. 7.

$$t_{pb} = \frac{C_{inv}}{S_{yBat} - C_m} \quad [\text{years}] \quad (\text{Eq. 5})$$

$$C_{inv} = \frac{C_{yInv} \times t_{bat}}{C_{inst}} \quad [€] \quad (\text{Eq. 6})$$

$$S_{yBat} = E_{dBat} \times C_{gp} - C_m - C_{yInv} \quad [kW] \quad (\text{Eq. 7})$$

Financial scenarios

Scenario 1, a decreasing net metering agreement. The current proposal of the Dutch government is to set in place a decreasing net metering agreement after 2022 that will run until 2031. The percentages of delivered energy that can be balanced with the imported energy of the grid will decrease every year [5]. The percentages of energy delivered to grid that can be balanced in relation to the imported energy from the grid are shown in table II.

Table II: Proposal net metering agreement from 2023 and on

| Year | Percentage |
|------|------------|
| 2023 | 91% |
| 2024 | 82% |
| 2025 | 73% |
| 2026 | 64% |
| 2027 | 55% |
| 2028 | 46% |
| 2029 | 37% |
| 2030 | 28% |
| 2031 | 0% |

Scenario 2, no metering agreement. In the second scenario there is no metering agreement, the energy that is delivered to the grid cannot be balanced with the energy that is imported from the grid. As a consequence all energy delivered to the grid is paid at €0.07 and all energy imported from the grid is paid at €0.22.

Scenario 3: no metering agreement and variable wholesale energy prices. The energy that is taken from or delivered to the grid is bought or sold at hourly day-ahead electricity prices. Currently there are no plans for letting consumers buy and sell electricity at variable wholesale prices. However, because of the great variance on the energy prices at the wholesale market new mechanisms are being set in place to pass the effect of the price variability to the consumer market prices. Simulating this hypothetical scenario allows to anticipate what will happen if there was a direct relation between the two markets.

RESULTS

In scenario 1 in the first 4 years adding a battery will not save energy costs, Fig. 3. This is the case because in the first years it is still possible to balance a considerable amount of the delivered electricity to the grid with the imported electricity. With the consequent difference in costs. At the end of the decreasing net metering agreement program on average the savings are €205,- a year. If the battery was installed in 2021 the payback time for a 8 kWh battery would be of 16 years.

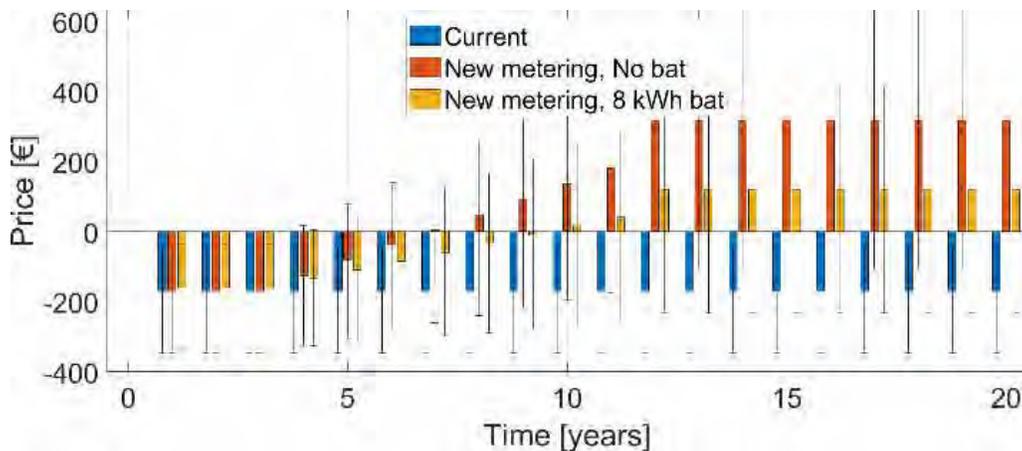


Figure 3: Energy price current metering agreement compared to new metering agreement

In scenario 2, without net metering agreement, NZEB households can deliver energy to the grid only at a selling price of €0.07kWh, what makes it economically interesting to add a battery immediately. Every year €205 will be saved on energy costs compared to the situation without a battery. In this scenario the payback time of the battery would be of 7 years.

In scenario 3 there is no net metering agreement and energy is sold and bought at day ahead wholesale prices. In this scenario it is not profitable to add a battery system to a NZEB household. With the wholesale prices of 2019 there is a yearly energy cost savings of €4. Therefore the payback time from the battery system is longer than the lifetime of the battery system.

However, it should be noted that wholesale electricity prices are considerable lower than consumer prices, in 2019 the average price for a kWh in the wholesale market was of €0.04. It should be also taken into account that the price variability and the average price in the wholesale electricity market has tripled in the last two years [8]. Lastly, the battery system simulated has not control system implemented, therefore, the battery charging and discharging periods are not cost optimized.

CONCLUSION

Until the end 2022 the current metering agreement will stay active, this results in high benefits for delivering energy back to the net. When the government will decrease the percentage of energy delivered to the grid that on a year basis can be balanced with the energy imported from the grid it will become more and more beneficial to add a battery. It is needed to take into consideration that all calculations have been done with an ideal battery. To create a more accurate model it would be necessary to add battery characteristics like:

- Batteries degrade over time and this is determined by the amount of power cycles.
- Batteries lose charge over time.
- Batteries can only be charged by a certain amount of power at the time.
- Batteries can only be discharged by a certain amount of power at the time.

These characteristics can make a difference to the outcome of how beneficial a battery system could be. Also the financial model should be further improved. Interest rates and later investment costs if battery reaches end of life should be included.

With the listed limitations taken into account the following can be concluded:

1. While the current metering agreement stays in place adding a battery to a NZEB energy system will not be profitable. Saving energy will cost more than delivering it back to the grid.
2. When the new metering agreement plan will be introduced adding a battery now to a NZEB energy system will be profitable if battery life can withstand for more than 16 years. Payback time of an 8 kWh will be 16 years.
3. When the metering agreement will be completely stopped it will become profitable right away to add a battery. With a battery capacity of 8 kWh the payback time will be of 7 years. If the trend of decreasing battery prices will go on, the payback time will be even shorter.
4. Scenario 3, no metering agreement and variable wholesale prices is not economically interesting if the battery system does not come equipped with a charge and discharge control system that allows to discharge the battery only on the most economically profitable periods of time.

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EFFECTIVENESS OF GREEN URBAN SURFACES TO MITIGATE EXCESS HEAT DURING HEATWAVES

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ABSTRACT

Heatwaves cause the second-largest number of deaths from Australian natural disasters. Human thermal comfort is a priority in heatwaves, along with the undue burden on energy demand. The heatwave impacts for cities could be intense due to energy budget changes with urbanisation and Urban Heat Island (UHI) effect. This paper investigates the effectiveness of green surfaces during heatwave events by arguing that the city will perform better with more green for excess heat. The study was conducted in the City of Melbourne during the well-documented two heatwave events in 2009 (28-30 Jan) and 2014 (14-16 Jan). The Air Pollution Model (TAPM), coupled with an urban canopy model, was used to simulate heatwave events with 1 km resolution, with different urban green surfaces such as urban trees and green roofs. Nine different scenarios were tested with individual and combined vegetation strategies of urban trees and green roofs (the existing urban setting T2 as the control). The combined scenario of C3 with maximum green roof fraction performed better of highest reductions for different temperature variables. Green roofs and combined scenarios were more effective at nighttime temperature reduction than during the day. Some scenarios with combined vegetative strategies performed better at some points, and in contrast, individual strategies are effective in some scenarios, proving non-synergistic behaviour. However, we emphasise green surfaces in cities as potential mitigation strategies to drop the day and nighttime temperatures in heatwave events.

KEYWORDS

Heatwave, Urban Green Infrastructure, Green Surfaces, Heat mitigation, Green roofs

INTRODUCTION

The current world population of 7.7 billion (2019) is projected to reach 8.5 billion in 2030 and 9.7 billion in 2050 [1]. With that growth, the current urban population of 55.3 % (2018) of the world's population is expected to increase to 68% by 2050 [2]. The United Nations says that the 'growth of urban population is driven by an overall population increase and the upward shift in the percentage living in urban areas [2]'. Dwelling and accommodating this increasing urban population is challenging and has already been considered through the 11th Sustainable Development Goal (SDG), making cities inclusive, safe, resilient and sustainable.

Extreme heat events impose many threats on human health, the environment, economy and infrastructure. For example, the most recent heatwave that happened in North America from 25 June to 1 July 2021 caused more than 500 excess deaths in the Western Canadian province of British Columbia, with 180 wildfires [3]. Australia is vulnerable to frequent heatwaves over its history. Therefore, heatwaves are worthy for spotlighting since it is predicted to increase the intensity, frequency, and duration in the future under augmented global warming [4], [5]. Heatwaves define when maximum and minimum temperatures that are atypical for a particular location are prolonged for three or more consecutive days. It is a natural hazard causing 55 % of all natural disaster-related mortalities in Australia [6]. For example, 374 people were dead during the 2009 Victorian heatwave, Australia [7]. In urban areas, the typical higher temperatures than suburban and rural areas (Urban Heat Island effect; UHI) can be heightened with heatwaves; therefore, heatwaves are severe in cities. Hence, adaptation and mitigation measures for heatwaves should be initiated at the urban planning level for better and more resilient future cities.

Some urban factors related to urban geometry and thermodynamics impact the heat inside cities [8]. The building fabric, urban geometry, building form, construction materials, thermal properties, and anthropogenic heat generate high heat in cities [9]. Whilst improper urban planning delays the natural processes to cooling down. When heatwaves occurred where cities already with high heat and UHI, the impacts escalate and are fatal. Previous studies from the literature have proved that urban expansion and built-cover surface materials directly impact urban heat during heatwaves [8]–[11].

The City of Melbourne is the second most populated city in Australia and Oceania. It is fastest growing and expected to be expanded to support the increasing urban population in future. Melbourne is populated currently with 183,756 in 2020 within a 37.7 km² area and projected to grow to 380,000 by 2041 [12]. However, we expect to increase more built-up areas in urban which increase the urban built-cover density. Urban green surfaces are proved to be efficient for reducing urban heat while providing other environmental, social, economic and aesthetical benefits [10], [13]–[15]. A study performed with Weather Research and Forecasting (WRF) model by Imran et al. (2019) assessed the effectiveness of green roofs and vegetative patches in Melbourne during a heatwave event [9], [10]. In addition, a modelling study by Jacobs & Gallant (2018) has evaluated the impact of cool roofs and vegetation on human thermal stress in Melbourne [11]. Supporting those studies, this paper will assess the possible maximum cooling potential that different urban green surfaces can achieve as an individual or combined scenario. We used the famous black summer heatwave event in 2009 and 2014 heatwave as case studies.

METHODS

Study area

Melbourne, our study site, is a coastal city located in southeast Australia. The city belongs to oceanic climate (Cfb) conditions following Köppen climate classification. Figure 1 shows how TAPM recognises the simulating area in 1 km grid resolution.

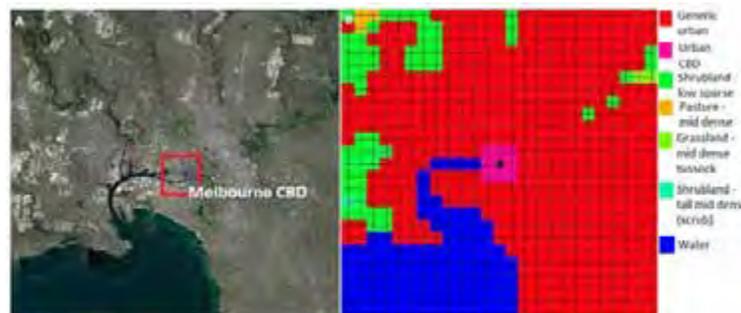


Figure 1: Melbourne urban area with the CBD from UCLEM-TAPM (A: Melbourne from Google Earth; B: TAPM representation; the black point represents the centre of CBD for temperature extraction)

Modeling software

This study used The Air Pollution Model (TAPM) developed by CSIRO, Australia, as a mesoscale, regional climate model to simulate Melbourne metropolitan area. TAPM was coupled with the Urban Climate and Energy Model (UCLEM) defined for Australian cities to include urban characteristics into the climate model. We intentionally select TAPM considering the advantages of running simulations without observational data, using user-defined surface cover databases and operating in PC-based Windows operating system [16]. TAPM-UCLEM can represent different urban forms with varying canyon geometries, thermal characteristics of building materials, vegetation fraction and tree heights [17]. Moreover, we applied nesting grid levels of 30, 10, 3 and 1 km in this study. TAPM supports 38 different surface types, including vegetation (shrubs, forests and grass), water, snow, urban (low density urban, CBD, industrial), and flexible for simulating multiple land-use types. This study was performed on 25×25 grid layers for each horizontal nesting level for 8 km vertical height.

The planned simulations were conducted for 2008-09 and 2013-14 summers, December to February (DJF), to include the heatwaves that occurred on 28-30 January and 14-16 January, respectively. The simulation timeframe was from November to February to give a one-month spin-in time to obtain the equilibrium. TAPM uses multiple sources for obtaining data for simulations. For few examples, TAPM receives MODIS satellite data, terrain data from US Geology Survey – Earth Resources Observation and Science (EROS) and Geoscience Australia. Model validation is essential for proving the model's suitability for use in a particular region. Since TAPM has been proved to be suitable for modeling simulations in Melbourne by a recent study by the same authors of this paper in Herath et al. (2021) [8], we have not repeated the trials and consider TAPM is valid to use for Melbourne.

Experimental design

We performed the experiments with three main strategies, urban trees, green roofs and combined both. The scenarios were named as they change the fractions of green surfaces, as shown in Table 1. The changes are made inside the CBD; however, the built-up ratio was maintained equal to keep a similar thermal impact from the built cover. The control, T2, represents the existing urban setting in Melbourne. Values for the existing set-up are adopted from Coutts et al. (2007) [18], and TAPM also uses these values as defaults. Green roofs percentages were based on findings of Sharma et al. (2016) [19] for noticeable results.

Table 1: Summary of land cover variables in different scenarios; see Figure 1

| Scenario | Urban trees (Tr) | | | Green roofs (GR) | | | Combined | | | | | |
|--------------------|------------------|---------------|--------|------------------|-----|-----|----------|-----|-----|-----|-----|-----|
| | T1 | T2 | T3 | G1 | G2 | G3 | C1 | | C2 | | C3 | |
| Remarks | Gr=0 | Control, GR=0 | +5% Tr | Tr = 15% | | | Tr | GR | Tr | GR | Tr | GR |
| % of each strategy | 0% | 15% | 20% | 50% | 70% | 90% | 20% | 50% | 20% | 70% | 20% | 90% |

RESULTS AND DISCUSSION

In this section, we present the results of the experimental case studies by providing a discussion. As an overview, we assessed the temperature differences between each scenario in different locations inside the modeling area while concerning the average diurnal temperature on heatwave days. Moreover, this paper illustrates the changes of 2 m above air temperature (T_{air}) among different urban scenarios.

Diurnal temperature for heatwave days

Heatwaves occurred on 28-30th January 2009 and 14-16th January 2014, and we assessed the different temperature variables such as average temperature (T_{ave}), maximum temperature (T_{max}) and minimum temperature (T_{min}) for that particular period. In Figure 2, the average hourly temperature in three heatwave days was plotted against the time of the day. Increasing urban tree ratio has been done in the model equally, inside the canyon (in roadsides, curbs) and outside the canyon (urban parks, gardens). Unlike the graphs in Figure 2A and 2D graphs (depicting tree ratio changes), scenarios with green roofs ratio and combined strategies show a reduction trend in diurnal curves. However, the daytime temperatures in CBD has not changed significantly with different scenarios, while the nighttime temperature has reduced compared to the T2, control.

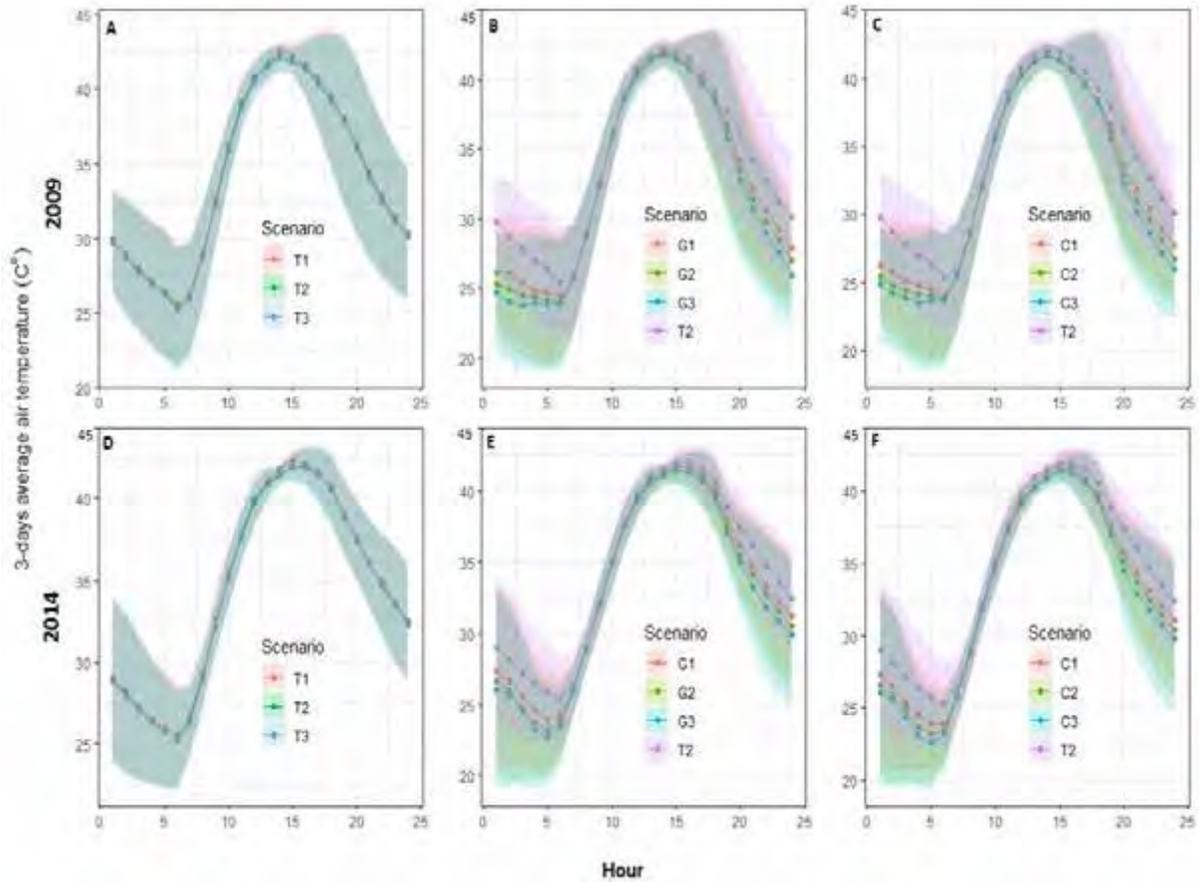


Figure 2: Average hourly air temperature (2 m above ground) in 3 heatwave days (28-30 Jan 2019);
 A, B, C: Diurnal air temperature for all scenarios in 2009 heatwave,
 D, E, F: Diurnal air temperature for all scenarios in 2014 heatwave (Shaded area represents one standard deviation)

Temperature variables T_{ave} , T_{max} and T_{min}

Table 2 presents the test results of the paired t-test conducted for each scenario's average air temperature, paired with the control, T2. The value for CBD centre was considered in the t-test during two heatwaves. T1 represents a no vegetation scenario in the modeling area, and it consistently has increased temperature than the control situation. Moreover, a temperature reduction was achieved for most scenarios (except T1) and proved statistically significant for both years. As illustrated in Figures 3, T_{ave} varies while changing the scenario. The most changes are proving a reduction in temperature variables and verifying the results of Table 2. The behaviour of T_{ave} for both green roofs and combined scenarios demonstrates a significant p-value for the paired t-test, and the mean values also show the expected reduction for both years. C3 proved to be the best option with the highest reductions of 2.09 and 1.69 °C, respectively, for 2009 and 2014.

However, increasing the urban tree ratio by 5 % (up to 20%) did not make a significantly large change for T_{ave} . An increase by a smaller ratio of 5% for urban trees might not be substantial and sufficient and could be caused for these insignificant temperature results. Alternatively, this increment is done only in a smaller area, only in CBD, and this might not make substantial changes in the temperature variables. Based on these observations, further studies should be conducted to decide the effective urban tree versus urban built-up ratio for effective cooling.

Table 2: Results of paired t-test for average temperature for each scenario with the control, T2 for 3 days hourly temperature for 2009 and 2014 heatwaves (* shows the p-values with a significant difference, <0.05), reduction by mean difference is calculated as T2-Scenario

| Year | Control T_{ave} | Scenario | T_{ave} Mean (SD) | p-value | Reduction by mean differences (°C) |
|------|-----------------------|----------|---------------------|---------|------------------------------------|
| 2009 | T2 34.02 (6.55) | T1 | 34.25 (6.56) | <0.001* | -0.229 |
| | | T3 | 33.95 (6.54) | <0.001* | 0.071 |
| | | G1 | 32.90 (7.10) | <0.001* | 1.126 |
| | | G2 | 32.50 (7.32) | <0.001* | 1.524 |
| | | G3 | 32.12 (7.49) | <0.001* | 1.899 |
| | | C1 | 32.65 (7.09) | <0.001* | 1.376 |
| | | C2 | 32.27 (7.29) | <0.001* | 1.749 |
| | | C3 | 31.93 (7.46) | <0.001* | 2.092 |
| 2014 | T2 34.31 (6.28) | T1 | 34.52 (6.28) | <0.001* | -0.214 |
| | | T3 | 34.29 (6.32) | 0.520 | 0.011 |
| | | G1 | 33.46 (6.72) | <0.001* | 0.842 |
| | | G2 | 33.08 (6.92) | <0.001* | 1.228 |
| | | G3 | 32.76 (7.05) | <0.001* | 1.543 |
| | | C1 | 33.29 (6.73) | <0.001* | 1.011 |
| | | C2 | 32.93 (6.90) | <0.001* | 1.375 |
| | | C3 | 32.61 (7.01) | <0.001* | 1.694 |

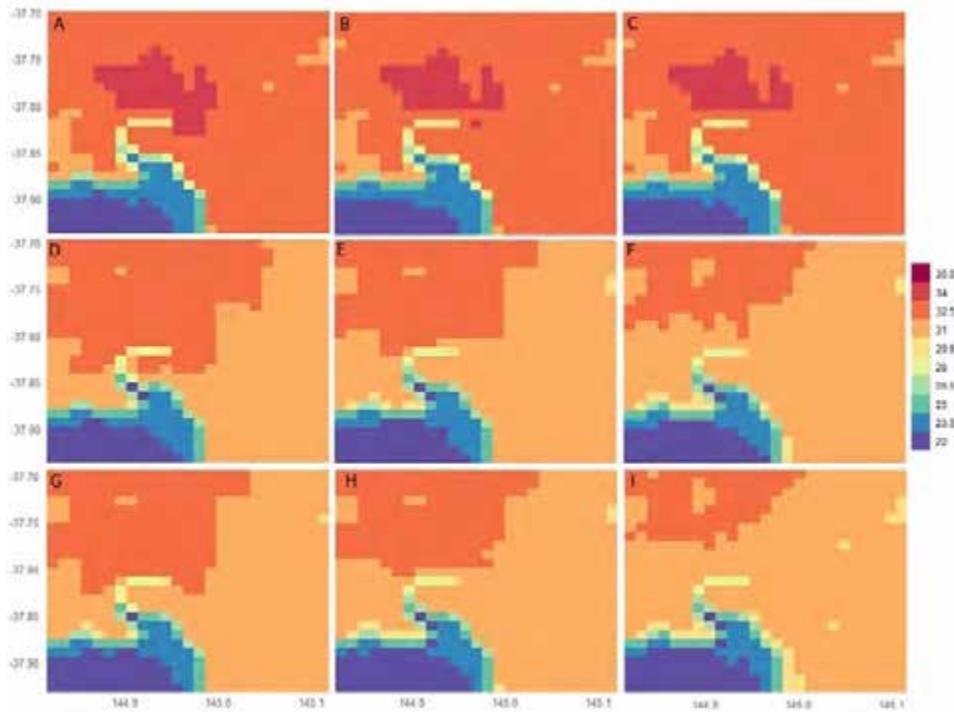


Figure 3: Mean average temperature (T_{ave}) for three heatwaves days in 2009 across the modeling area (B = T2, control and the rest is T1, T3, G1, G2, G3, C1, C2 and C3 in order of A to I)

As shown in Table 3, for T_{max} C3 and G3 scenarios proved effective with higher temperature reduction (ranged from 0.5 – 0.9 °C) and T_{min} have decreased in higher reductions ranged from 1.4 – 3.4 °C. C3 has performed its highest capable reduction of 0.9 °C in 2014; however, it is noticeable that the contribution of all green options to reduce T_{max} is less in figures compared to T_{ave} and T_{min} . All scenarios with green roofs and combined options have performed effectively to minimise the T_{min} , while G3 and C3 report the highest reductions for different days without a proper visible pattern (for example, in 2009, C3 records the highest reduction 2.9 °C for day 1 when G3 performs 3.5 °C for day 3). Figure 4 represents the changes for T_{max} and T_{min} with different scenarios.

Since Melbourne is already a developed city, urban planners must consider and plan strategically how to utilise the urban spaces for urban green infrastructure (UGI). According to the default values of TAPM (based on [18]), Melbourne CBD already occupies 65 % of the built-cover with 15 % urban trees. This space sharing then keeps 20 % for roads and impervious paving inside CBD, and this is the limiting factor to increase the vegetation ratio. That is the justification for using a 5 % increment of urban tree ratios in the simulation. Therefore, saving that total 20 % or 15 % for road infrastructure, we planned alternative strategies with green roofs and combinations (G1, G2, G3, C1, C2 and C3) to overcome the practical difficulties.

Table 3: Differences of maximum and minimum temperatures for 3 heatwave days, calculated as T2 minus scenario for both heatwaves in 2009 and 2014. All values are mentioned in °C

| T | Scenario | 2009 | | | | | | 2014 | | | | | |
|-----------|----------|-------------|------|-------------|------|-------------|------|-------------|------|-------------|------|-------------|------|
| | | Day1 | | Day2 | | Day3 | | Day1 | | Day2 | | Day3 | |
| | | Value | ΔT |
| T_{max} | T2 | 41.8 | | 43.2 | | 42.7 | | 42.3 | | 41.1 | | 43.0 | |
| | T1 | 42.2 | -0.4 | 43.3 | -0.1 | 42.9 | -0.2 | 42.4 | -0.1 | 41.5 | -0.4 | 43.1 | -0.1 |
| | T3 | 41.8 | 0 | 42.8 | 0.4 | 42.7 | 0 | 42.6 | -0.3 | 41.3 | -0.2 | 42.9 | 0.1 |
| | G1 | 41.5 | 0.3 | 42.8 | 0.4 | 42.5 | 0.2 | 42.2 | 0.1 | 40.8 | 0.3 | 42.5 | 0.5 |
| | G2 | 41.5 | 0.3 | 42.8 | 0.4 | 42.3 | 0.4 | 42.0 | 0.3 | 40.6 | 0.5 | 42.4 | 0.6 |
| | G3 | 41.3 | 0.5 | 42.6 | 0.6 | 42.2 | 0.5 | 41.8 | 0.5 | 40.4 | 0.7 | 42.3 | 0.7 |
| | C1 | 41.4 | 0.4 | 42.4 | 0.8 | 42.4 | 0.3 | 42.3 | 0 | 40.7 | 0.4 | 42.4 | 0.6 |
| | C2 | 41.4 | 0.4 | 42.6 | 0.6 | 42.3 | 0.4 | 42.2 | 0.1 | 40.5 | 0.6 | 42.2 | 0.8 |
| | C3 | 41.2 | 0.6 | 42.6 | 0.6 | 42.1 | 0.6 | 41.8 | 0.5 | 40.7 | 0.4 | 42.1 | 0.9 |
| T_{min} | T2 | 20.8 | | 28.4 | | 25.3 | | 22.0 | | 27.9 | | 26.0 | |
| | T1 | 21.0 | -0.2 | 28.7 | -0.3 | 25.5 | -0.2 | 22.3 | -0.3 | 28.3 | -0.4 | 26.2 | -0.2 |
| | T3 | 20.6 | 0.2 | 28.4 | 0 | 25.2 | 0.1 | 22.0 | 0 | 27.8 | 0.1 | 25.9 | 0.1 |
| | G1 | 19.3 | 1.5 | 28.1 | 0.3 | 23.8 | 1.5 | 20.7 | 1.3 | 26.6 | 1.3 | 23.8 | 2.2 |
| | G2 | 18.8 | 2.0 | 27.6 | 0.8 | 22.9 | 2.4 | 20.0 | 2.0 | 25.6 | 2.3 | 23.2 | 2.8 |
| | G3 | 18.4 | 2.4 | 27.0 | 1.4 | 21.8 | 3.5 | 19.4 | 2.6 | 24.5 | 3.4 | 22.6 | 3.4 |
| | C1 | 19.0 | 1.8 | 28.1 | 0.3 | 23.6 | 1.7 | 20.7 | 1.3 | 26.5 | 1.4 | 23.8 | 2.2 |
| | C2 | 18.5 | 2.3 | 27.4 | 1.0 | 22.7 | 2.6 | 20.0 | 2.0 | 25.5 | 2.4 | 23.2 | 2.8 |
| | C3 | 17.9 | 2.9 | 27.0 | 1.4 | 21.9 | 3.4 | 19.4 | 2.6 | 24.5 | 3.4 | 22.8 | 3.2 |

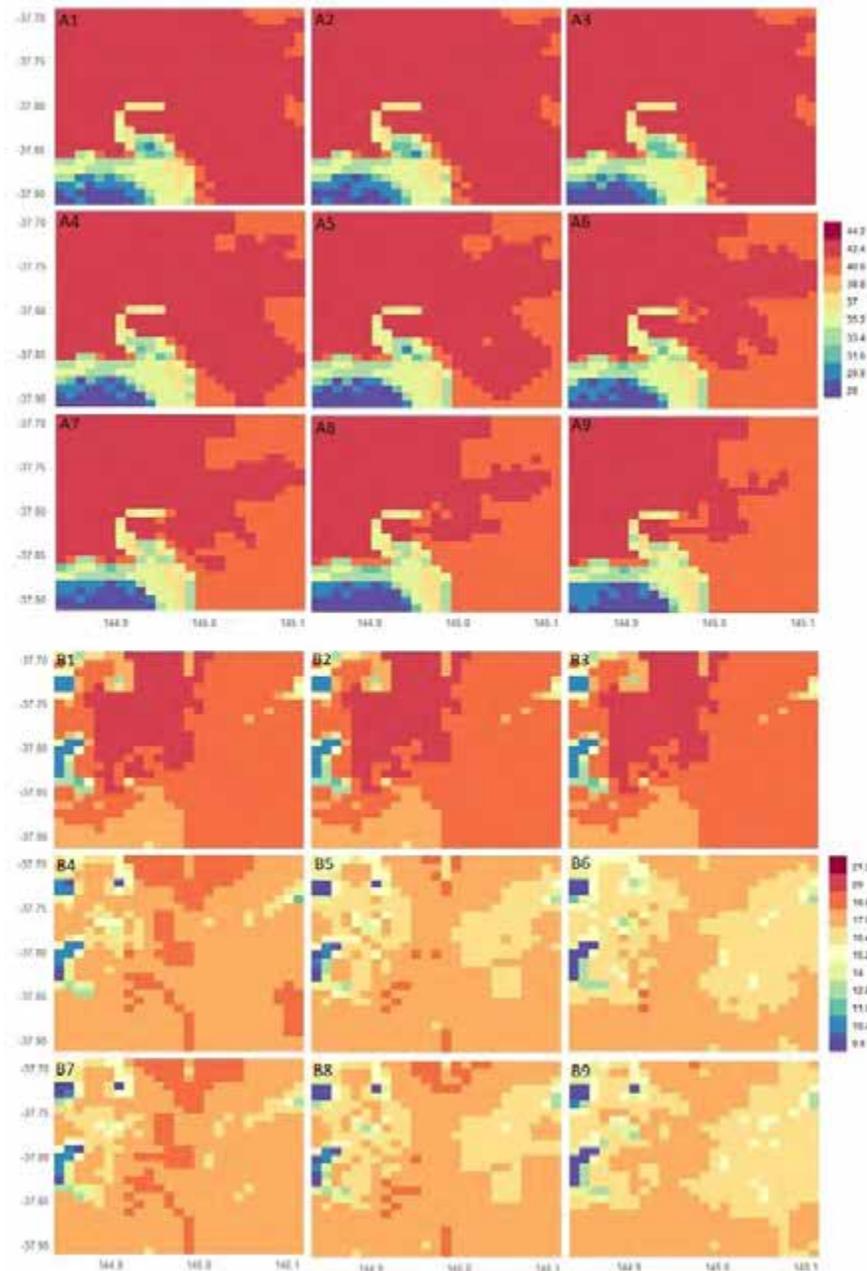


Figure 4. Mean maximum and minimum temperatures for 3 heatwave days in 2009 across the modeling area (A: T_{max} , B: T_{min} ; A2 and B2= T_2 (control) and the rest is T1, T3, G1, G2, G3, C1, C2 and C3 in order of A to I)

Areas around water record lower temperatures as those regions continuously cool down with evaporative cooling (Figure 3). It is noticeable that the temperatures are rising in urbanised areas and getting intense with higher built-cover urban densities. Built-up urban areas consisting of different materials such as concrete, asphalt, metal, wood, and some materials reduce the reflection of solar radiation and then promote storing it as heat energy [20], [21]. This process can alter the energy balance inside a city, and then cities become hotter than surrounded areas. This phenomenon is called as Urban Heat Island (UHI) effect. Then heatwaves in cities are more severe than rural, due to this UHI effect, and it directly challenges human thermal comfort by increasing the vulnerability. Mostly we identify UHI in cities during the night. Because of that, we use minimum temperature values as a measure of UHI. As proved through our results, vegetative surfaces are highly effective in decreasing the minimum or nighttime temperature. Therefore, as a significant conclusion of this study, we present that the urban green surfaces are highly effective for mitigating the impacts of excessive heat due to intensified UHI during heatwave days.

When we introduce greener surfaces to cities as urban trees and green roofs (in this particular study), the modelling area's temperature profile has undoubtedly changed. This cooling ability is promoted through 3 natural processes supported by vegetation; evapotranspiration, moisture availability and shading [22], [23]. Evapotranspiration and moisture availability support latent heat and sensible heat fluxes reduction, while shading can block the incoming solar radiation [22], [24]. According to our results, the scenarios with green roofs are highly effective because roofs cover a substantial fraction of the city [8]. Then it makes a larger green area to provide higher evaporative cooling. Although urban trees have not demonstrated significant results individually, the increased 5% urban tree fraction positively affects when added in combined scenarios. All combined scenarios have higher values than individual scenarios, except for T_{\max} in 2014. This different process is introduced as nonsynergistic by Jacobs *et al.* (2018) [11]. They identify this as 'the cooling occurring from the combination of both strategies is either larger or smaller than if the cooling from individual strategies were to be added together' [11].

The Jacobs *et al.* (2018) study used the regional climate model, Weather Research Forecasting (WRF) model [11]. That simulation study is also consistent with our findings of the effectiveness of increased vegetation during nighttime and fewer reductions during the daytime. Sharma *et al.* (2016) conducted a study in the Chicago metropolitan area, the USA, with green roofs to reduce temperature [19]. The daytime roof temperature has decreased in the range of 1 - 3 °C by 25 – 100 % green roof ratios during peak daytime [19]. In the Australian context, Imran *et al.* (2019) simulated Melbourne in WRF with vegetation patches. The temperature has reduced in a range of 0.4 - 3.7 °C during heatwaves in different ratios and scenarios [25]. Another study from the same authors has tested the cooling capacity of green roofs in Melbourne for roof surface UHI and reported a reduction from 1 - 3.8 °C during the day by increasing green roof fractions from 30 to 90 % [10].

LIMITATIONS AND CONCLUSIONS

The study was performed to assess the effectiveness of urban green surfaces to mitigate excess heat during the Melbourne heatwaves. We compared nine different scenarios, including the T2 – control using a climate model simulation. As the main limitation of the study, implementing higher ratios such as 90 or 100% is not practically feasible. Therefore it is essential to convert these experimental strategies to practical implementations. Moreover, these results could be specific to Melbourne with its climatic and geographical conditions. From our results, the maximum urban tree and green roof ratios were represented in C3 (20% and 90%, respectively) offer the highest temperature reductions for T_{ave} , T_{max} and T_{min} . The results have proved the higher efficacy of green roofs scenarios and combined options during nighttime, suggesting better UHI adaptation strategies. As results depict, a 20% ratio is not sufficient to achieve maximum cooling benefits through urban trees, and in this particular study, we are unable to increase the amount with the available urban setting. Then the combined scenarios can be helpful to obtain the maximum possible cooling for a city. We conclude by proposing that urban green is an effective strategy to adapt to excess heat conditions during heatwaves.

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PROMOTING BIO-BASED BUILDING MATERIALS AS A MEANS OF BRIDGING THE URBAN-RURAL DIVIDE IN SERBIA

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ABSTRACT

Due to the difficult economic situation within Serbia, rural areas find themselves on the margins of investment and development, creating a deep rural-urban divide. Much of Serbia can be characterized as rural with a large segment of the population living in rural settlements defined by socio-economic stagnation or degradation. Revitalizing rural regions is thus important for the socio-economic wellbeing of the entire country and mitigating the rural-urban divide can be key to the sustainable development of urban areas. Much of the built environment in Serbia has a low level of energy efficiency and though public perception has improved, the focus is on improving operational energy, while the embodied environmental impact of building materials is rarely considered. This paper details and analyses the main problems facing rural areas in Serbia. As agriculture is still the primary economic activity in rural areas, it suggests that the development and application of bio-based building materials created from the by-products of agriculture, can be an important element of further strategies for sustainable development in Serbia. In particular industrial hemp, which was once an important and abundant crop in Serbia, is currently experiencing a significant resurgence. This paper demonstrates that hemp-lime concrete may be a particularly suitable building material for encouraging new economic activity in rural areas and promoting sustainable design in both rural and urban areas.

KEYWORDS

Urban-Rural divide, Rural Development, Bio-based building materials, Industrial hemp, Hemp-lime concrete

INTRODUCTION

Representations of the rural have differed throughout history and are dependent on a wide range of influences. Traditionally the rural may be associated with nature, agriculture and community life, but no universal definition exists. The rural is thus a complex, contested and ambiguous space which has been defined through various conceptual approaches and definitions over the years. Though interconnected, the rural has also generally been seen as separate from the urban and has often been defined negatively as non-urban or as subservient to the urban. In Serbia, since 1981, settlements have been classed as either “urban” or “other” based on the administrative decisions of local government offices. Of 6158 settlements, 193 are classed as urban, while the other 5956 can be considered rural [1]. Though they aren’t clearly or universally defined, rural spaces and rurality still hold a prominent place in the social consciousness of Serbia. Unfortunately the unfavourable economic situation in the country has particularly affected rural areas and has led to their socio-economic degradation. Though urban areas have also suffered, in general they are able to provide a higher quality of life to their residents. These spatial and socio-economic divisions have engendered a deep rural-urban divide, which has also been fostered on a political level, as rural areas are marginalized and left without the institutional and economic support required for their continued development and wellbeing. Rural areas are home to 39.8% [2] of the population, thus it is clear that improving their socio-economic standing is also key for the overall development of country.

The socio-economic deprivation inevitably also has a negative effect on the natural and built environment. The national strategy for rural development is primarily centred on agriculture, as defined in “The Strategy for agricultural and rural development of the Republic of Serbia 2014-2024” [1]. The five main strategic goals aim to increase producer income, introduce technological advancements into agriculture, improve environmental protection, implement sustainable resource management, reduce poverty, improve the quality of life in rural areas and improve the institutional framework for rural development. The production of bio-based building materials from the by-products or co-products of agricultural production can be seen as a part of these wider strategies and can have wide reaching benefits for both rural and urban areas. Bio-based building materials make use of renewable and biodegradable components that sequester carbon dioxide from the atmosphere through photosynthesis. Though socio-economic differences between rural and urban areas may be pervasive, the differences in single family housing typology are not as pronounced. Studies into the typology of family housing in Serbia [3,4], have shown that most of the existing single family housing stock was built in the second half of the 20th century, when environmental sustainability and energy efficiency were low design priorities. As Jovanović Popović et al. [3] indicate, since the 1970s the same housing typologies can be found in all regions of Serbia, thus the same comfort and energy efficiency issues permeate both rural and urban areas. The main aim of this study is to analyse the opportunities and implications of introducing bio-based building materials into construction practices in Serbia as a means of promoting rural development. As industrial hemp is currently experiencing a resurgence in Serbia, the paper will primarily focus on lime-hemp concrete.

THE RURAL – URBAN DIVIDE IN SERBIA

The initial draft document for the “Spatial Plan of the Republic of Serbia 2021 to 2035” [5], indicates that despite the existence of previous spatial plans and strategies, polarization between large urban centres and smaller urban centres and rural areas, still persists. Key statistics demonstrating the socio-economic disparities between rural and urban areas are shown in Table I.

Table I: Key socio-economic statistics of rural and urban areas in Serbia

| | Urban | Other (Rural) |
|---|-----------------------------------|----------------------|
| Population 2011[2] | 59.1% | 40.9% |
| Population 2020 [2] | 60.2% | 39.8% |
| Average age [2] | 42.4 | 45.1 |
| Monthly monetary household income, 2019 [6] | 68765 RSD | 57885RSD |
| Absolute poverty rate, 2016 [7] | 5.1% | 10.5% |
| Risk of poverty, 2020 [8] | 14.6 - 18.1% depending on density | 30.7% |

Due to a low natality rate, an aging population and a high rate of emigration, Serbia is faced with a declining population. It is estimated that the population has fallen by around 4.7% between 2011 and 2020, with depopulation predominantly affecting rural areas. During this period only the region of Belgrade, consisting of the capital city and its surrounding areas, achieved population growth. Based on the results of the last national census in 2011, rural areas had a worse overall level of education with a higher percentage of residents without a formal education and a lower percentage with a higher education [9]. Thus though the whole country is facing a demographic crisis, rural areas in particular, are being affected by a loss of human capital. The region of Belgrade is responsible for the production of 41.7% of the total national GDP with an average GDP that is 70.8% higher than the national average [10]. This is indicative of the effects of centralisation and the level of financial disparity between primarily urban and rural regions. On average households in urban areas have a 15.8% higher monetary income, than rural households [6]. The absolute poverty rate and risk of poverty is also much higher in rural areas, than in urban areas. Centralization and uneven development have left many rural areas devoid of services, infrastructure and economic opportunities, which has in turn led to their socio-economic degradation.

Agriculture is still the primary economic activity in rural areas and is seen as the primary sector through which any rural development can be enacted. Table II and III present key statistics describing the structure of farm holdings in Serbia.

Table II Key statistics for farm holdings in Serbia 2012 & 2018 [11]

| Year/ Total farm holdings | Total associated workers | Family holdings | | | Legal entity holdings | | | Total averages | |
|------------------------------------|--------------------------------|-----------------|----------------------|-----------------------------------|-----------------------|----------------------|-----------------------------------|----------------|---------------------------|
| | | Total (%) | Average Size (ha) | Average standard output (€) | Total (%) | Average size (ha) | Average standard output (€) | Size (ha) | Standard output (€) |
| 2012/ 631552 | 1416349 | 99.5 | 4.48 | 4990 | 0.5 | 204.12 | 204755 | 5.44 | 5939 |
| 2018/ 564541 | 1318593 | 99.7 | 5.2 | 7470 | 0.3 | 364.20 | 398518 | 6.16 | 8610 |

Table III The composition of farm holdings in Serbia according to size [12,13]

| Year/ Total farm holdings | 0-2ha | | 2.01-5ha | | 5.01-10ha | | 10.01-50ha | | 50.01-100ha | | >100ha | |
|------------------------------------|--------------|--------------------|--------------|--------------------|--------------|--------------------|--------------|--------------------|--------------|--------------------|--------------|--------------------|
| | Share (%) | Land use (%) |
| 2012/ 631552 | 48.12 | 7.7 | 29.3 | 17.32 | 14.29 | 18.03 | 7.29 | 24.13 | 0.69 | 9.03 | 0.28 | 23.8 |
| 2018/ 564541 | 39.15 | 6.29 | 32.8 | 16.95 | 17.05 | 19.13 | 10.27 | 30.08 | 0.68 | 7.37 | 0.25 | 20.16 |

The 2018 agricultural poll reported a 10.6% reduction of farm holdings, compared to the last agricultural census in 2012 [11]. Though the total number of people associated with any degree of agricultural work has fallen, the average number of workers per holding has risen. As around 99.7% of holdings are considered “family holdings”, few people are employed as full time workers with most of the workforce being made up of farm owners, their families and day labourers. However only 10.7% of the total income of the average rural household came from agriculture, which is down from 13.3% in 2012 [6]. Income from full time employment and pensions accounts for a higher percentage of household income, showing that many rural residents are employed in other sectors and use agriculture as a means of gaining an additional income. This is reflected by the small size and low value of many family holdings. Though farm holdings appear to have gotten slightly larger, with a relative increase in medium to large holdings (5-50ha), overall they are still relatively small. Farm holdings under 5 hectares, still make up the majority of farm holdings even though they use less than a quarter of the cultivated agricultural land. The small size of the farm holdings is compounded by their low value. The average standard output in 2018 was €8610, which is very low compared to an average standard output of €34785 by EU farm holdings in 2016 [13]. There is a vast difference in size and output between

the average family and legal entity holdings. With the largely extensive nature of production and so many farm holdings of low standard output, agriculture in Serbia is particularly sensitive to the effects of climate change [1]. While the primary national development strategies [1,5], highlight the importance of improving the sustainability and environmental effects of current farming practices, little mention is made of the potential benefits of using agricultural crops for creating more environmentally friendly products. Though growing crops for biofuels is mentioned, the use of agricultural by-products and co-products for making bio based-building materials, is not discussed.

INDUSTRIAL HEMP CULTIVATION

Interest for industrial hemp has been growing worldwide as a result of the need for more sustainable raw materials and the increased demand for CBD (cannabidiol) in the pharmaceutical industry. Industrial hemp is a versatile crop, as every part of the plant has commercial uses. The plant can grow up to 5 metres tall and has a thin stalk which consists of a hollow woody core on the inside and the bark, which contains fibre bundles, on the outside. The fibres are used for making industrial textiles, paper, thermal insulation and technical fibre in various biocomposites. The seeds and the oil extracted from the seeds can be used for producing various food products, dietary supplements, cosmetics and other various industrial products. The flowers are primarily sought by the pharmaceutical industry for CBD, which is used in various novel medical products. Finally the woody core or shivs are the co-product of fibre extraction and are used as animal bedding, mulch and a primary raw material for hemp-lime concrete. Industrial hemp is quite resilient, as it doesn't require the use of pesticides and herbicides. It is also adapted to a wide range of soil and climate conditions and can be used in rotation with other crops [14]. One can agree with Stanwix and Sparrow [15], that though industrial hemp shouldn't be considered a "miracle crop" which can resolve all the problems of the modern world, it possess many advantages and it could be an important material for creating more sustainable products in the future.

The soil and climate conditions in Serbia are suited for industrial hemp cultivation. This is reflected by the rich historical context of industrial hemp production. During the early and mid 20th Century, as part of Yugoslavia, Serbia was one of the largest industrial hemp producers in Europe. From 1948 to 1952, an average of 70000 hectares was sown with around 70% of the crop cultivated in Serbia [16]. A steep decline in production began in the 1960s, which culminated in the closure of all processing plants and a cultivated area of only 60 hectares in 2015. Since then, interest in the crop has grown and production has risen steadily. It is estimated that around 1500 hectares were cultivated in 2020 and an increase to over 10000 hectares is expected in the coming years [17]. Potential limiting factors to further expansion, are the stigma surrounding the appearance of the crop and the need for licences and government control. The cultivation of industrial hemp requires a licence from the Ministry of Agriculture [18]. Though the terms could be more liberal, the requirements of the legislation are primarily of an administrative nature and shouldn't present an insurmountable barrier to anyone interested in growing industrial hemp. Therefore the main limiting factor will be the profitability of industrial hemp production and processing. With increased cultivation worldwide, competitiveness is key. Potentially lower production costs are an advantage, but the lack of cultivar diversity could be an issue. Currently, only six cultivars can be grown legally [19], which could potentially inhibit the future competitiveness of Serbian hemp products on the worldwide market. However, with the expected growth of production and the development of new processing plants, there is a great potential for manufacturing and using building materials from industrial hemp.

THE PROPERTIES OF HEMP-LIME CONCRETE

Though hemp fibres can also be combined with a polymer based binder to make insulation batts and boards, this study will primarily focus on hemp-lime concrete, as it is the most prominent and versatile building material originating from the hemp plant. Hemp-lime concrete or "hemcrete" is a composite building material made by mixing hemp shiv with a lime based binder and water. It was created in France in the 1980s as a replacement for wattle and daub in historic buildings and can be used in new construction, energy renovation and historical restoration [15]. Though it can also be used for roof and floor insulation, it is primarily used for wall construction. It isn't a load bearing material and has to be cast around a structural frame or applied to the surface of an existing solid wall. It is most often cast in situ around a timber structural frame, but can also be prefabricated into blocks or panels. Depending on density, hemp-lime concrete walls have a relatively low dry thermal conductivity of around 0.06 to 0.12W/mK [20]. This is notably higher than the thermal conductivity of typical thermal insulation materials such as stone wool and EPS, which usually varies from 0.03 to 0.04W/mK. However studies have shown, that due to its porous structure and hygroscopic nature, hemp-lime concrete possesses an excellent moisture

buffer capacity and good thermal inertia [20, 21, 22, 23, 24]. Under dynamic conditions, hemp lime concrete is able to buffer the effects of outdoor humidity and temperature variations, thus maintaining a stable and comfortable indoor environment and reducing the need for active climate control.

Hemp-lime concrete makes use of a renewable and biodegradable raw material, which had limited uses as mulch or animal bedding. During its short growth cycle hemp shiv sequesters carbon dioxide from the atmosphere, reducing the environmental impacts of the material. Existing LCA studies show that various functional units representing a 1m² wall of hemp-lime concrete cast around timber studs, sequester more greenhouse gases than they release and have a negative global warming potential (from -36.08kg CO_{2eq} [25] to -1.6kg CO_{2eq} [26]). Assuming a carbon content of 46% in hemp shiv [27] and a moisture content of 11% [28], 1kg of hemp shiv can sequester 1.5kg of carbon dioxide. The implications of using hemp-lime concrete in Serbia hasn't been sufficiently studied, as the construction of only one hemp-lime concrete building has been publicized, so far.

THE SINGLE FAMILY HOUSING STOCK AND CONSTRUCTION PRACTICES IN SERBIA

Single family housing is the dominant residential typology in rural areas and in Serbia as a whole (92.13% of the total buildings and 69.22% of the dwelling units [4]). Though there is a need to raise awareness about the benefits and need for energy efficiency, Jovanović Popović et al. [3] indicated that people were generally aware of the benefits of energy savings through improvements to the thermal envelope of their home. In the years since their study in 2012, energy renovation has become more prevalent. Though the difficult socio-economic situation in the country has made energy renovation more difficult and slowed down the ingress of environmental design principles. The energy efficiency of buildings is regulated by the "Regulations for the energy efficiency of buildings" [29], which primarily focuses on the operational energy of buildings. The embodied energy of building materials isn't taken into account as a means of improving the environmental sustainability of buildings. Buildings are certified with energy passports, which classify them into energy grades according to their final heating energy consumption [30]. Thus the construction context in Serbia is characterised by a large section of housing stock that doesn't satisfy current energy efficiency standards and current new build and renovation practices that don't take into account resource consumption and the embodied energy of building materials.

The oldest buildings in rural areas are examples of vernacular architecture built in the 19th century using wattle and daub or rammed earth. Construction using traditional techniques and materials ceased in the first half of the 20th century (Fig. 1).



Fig. 1. The house of Živojin Mišić in Struganik, an example of 19th century vernacular architecture in Serbia (own photo)

In 2013, family housing built before 1919 made up around 5% of the housing stock [4]. Unfortunately many of these buildings are in a bad state of disrepair and their restoration must primarily be approached as a means of preserving architectural heritage. As a vapour permeable material created as a replacement for wattle and daub, hemp lime concrete is ideal for both the physical reconstruction and energy renovation of Serbian vernacular architecture. Following the introduction of masonry in the early 20th century, rural areas started to look to urban housing for inspiration. Thus over the course of the 20th century differences in the construction, organization and appearance of urban and rural single family housing, disappeared (Fig. 2).



Fig. 2. Examples of typical 20th century single family housing in Serbia from 1971-2012 [4]

Much of the existing housing stock utilizes masonry construction and doesn't meet the requirements of the energy efficiency regulations. The primary aim of energy renovation practices is to meet or surpass the required thermal transmittance values for the thermal envelope, set by the regulations. In practice, this is primarily achieved using ETICS façade systems, which utilize stone wool or EPS insulation and are finished with thin layer silicon, silicate or acrylic renders. New buildings are also primarily constructed using hollow clay blocks or thermal clay blocks with an ETICS façade system. Thus both energy renovation and new construction primarily only focus on reducing operational energy through the use of inorganic and nonrenewable building materials. The choice of insulation materials is primarily driven by cost, which has also limited the variety of insulation products available on the Serbian market. As operational energy accounts for most of the energy used during a building's lifecycle, bio-based materials with a lower embodied energy, still need to match or exceed the operational performance of conventional building materials to be considered completely effective. Therefore, hemp-lime concrete constructions can only be considered superior to current practices in Serbia, if they have lower embodied environmental impacts at the same operational energy usage.

DISCUSSION

It can be argued that there is both an opportunity and need for the introduction of bio-based building in Serbia. Hemp-lime concrete in particular appears to be a material that can have a positive effect on agriculture and the built environment as whole. From the aspect of agricultural development, industrial hemp is an in demand crop that can be used to create a wide variety of products and presents many opportunities for the diversification of economic activities in rural areas. It can also contribute to more positive farming practices, as it doesn't require phytosanitary protection. Due to its vigorous growth industrial hemp also leaves the land clear of weeds and returns significant organic matter to the soil post harvesting [14]. A disadvantage is that it still requires the use of nitrogen, phosphorous and potassium fertilisers, which contribute to the emissions of ammonia, nitrates, nitrous oxide and phosphates. Though according to van der Werf [31] industrial hemp in general requires less nitrogenous fertiliser than sunflower, oilseed rape, wheat, corn, potato and sugar beet. The average yield of the local Helena cultivar is 10t/ha, which according to Bevan and Woolley [14] is enough to build one lime-hemp concrete house. Though the idea of occupying agricultural land for creating building materials may seem problematic, hemp shiv is simply a co-product of hemp fibre extraction and not the sole or primary product of industrial hemp cultivation. It is also important to note that in 2018 around 5.6% or 289953 hectares of the agricultural land held by farm holdings in Serbia wasn't cultivated [12], thus increased industrial hemp production need not jeopardize the cultivation of other crops.

It is important to note that though the production of industrial hemp is primarily tied to the agricultural sector, the development and production of hemp-lime concrete in Serbia is also dependent on the interest and cooperation of multiple industries. Processing plants would be required for hemp shiv extraction and binder production. An important question to consider, is whether a binder can be developed in Serbia using mostly locally produced raw materials or whether the established practice would be to import existing proprietary binders. Introducing hemp-lime concrete to the Serbian market, either through importing or manufacturing, is inherently a private endeavour. However, as Nozahic and Amiziane state [32] in order create a market for bio-based building materials, private actors may require the provision of help through financial incentives. This help may come from the state or local government in the form of tax incentives or subsidies to encourage people to use bio-based building materials.

Though current building regulations promote energy efficiency, they don't promote sustainability in a wider sense, by encouraging the reduction of embodied energy and effective resource management. Bio-based building materials can be useful in mitigating climate change and resource depletion. Therefore promoting materials such as hemp-lime concrete through changes to regulation and subsidies could become a part of national sustainability strategies. The low human, social and economic capital in rural areas makes starting endogenous development projects difficult and greatly limits their chances of success. Thus, as Bogdanov [33] and Mitrovic [34] argue, exogenous state interventions are almost certainly still required to raise the low level of territorial capital in rural areas and encourage development.

One further means of promoting bio-based materials in Serbia, might be to promote the use of hemp-lime concrete through building heritage restoration projects. Many traditional rural buildings require restoration and utilize wattle and daub construction. Architectural heritage is an important part of every nation's history and cultural identity and their restoration should be an important aspect of any rural development strategies. In addition, both the national rural development strategy [1] and spatial plan [5] highlight the potential role of cultural heritage in promoting rural tourism and the diversification of economic activities in rural areas. However hemp-lime concrete shouldn't be limited to rural areas and should be promoted as a material, which can be used in new construction and restoration throughout the country, opening up a knowledge transfer between urban and rural areas. Additionally, as thermal transmittance [20, 22] is not an adequate measure of the thermal performance of hemp-lime concrete, its operational performance cannot be adequately evaluated according to current building regulations in Serbia. Thus a willingness to adjust building regulations may also be a key to promoting the use of the material. One issue which may limit use of the material in practice is the lack of trained experts with experience in using hemp-lime concrete. Though this can also be an opportunity for the formation of new construction specialists and the transfer of new skills and jobs to rural areas. As hemp-lime concrete is an innovative and relatively new building material, reservations regarding the effectiveness of bio-based building materials may be a primary barrier to establishing a market. Ultimately it may be economic considerations and its cost effectiveness compared to conventional building materials that dictates the applicability of hemp-lime concrete in Serbia.

CONCLUSION

Rural areas in Serbia are characterised by socio-economic degradation and a largely energy inefficient housing stock. Centralised decision making and a lack of practical interest in rural development have created a measurable rural-urban divide. Though they shouldn't be regarded as the sole force for driving rural development, the promotion and implementation of bio-based building materials could be a means of furthering the concept of environmental sustainability in rural areas. Hemp-lime concrete appears to be a particularly suitable material, due to its versatility, carbon dioxide sequestration, positive hygrothermal behaviour and the growing interest in industrial hemp cultivation in Serbia. Industrial hemp is a multifaceted crop which can have a role in diversifying economic activities in rural areas, while hemp-lime concrete can have an important role in the restoration of architectural heritage and the reduction of embodied energy in the built environment. The impact and success of hemp-lime concrete in Serbia will primarily depend on its ability to match or exceed the thermal performance of conventional materials at a similar or lower price point. Studies regarding the applicability of hemp-lime concrete in the context of Serbia are crucial for its further promotion. It would be significant to analyse the operational performance of the material in the local climate through simulations or experiments and to analyse the environmental implications of making and using the material through a lifecycle assessment, which could also compare it to existing practices.

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NOVEL SMART GREEN SYSTEM FOR FARM TO FORK PRODUCTION ON BALCONIES AND TERRACES

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ABSTRACT

The global urban population is increasing (up to 9.8 billion people by 2050), thus the urbanization process has removed most people from food production and made them dependent on imported agricultural products. This has potential consequences for food security, greenhouse gas emissions, environmental sustainability and it is a risk for food supply in pandemic period. Therefore, there is the need to transform balconies and terraces into gardens able to produce horticulture and to improve urban climate, environment and resilience to disruptive events such as heatwaves and pandemics.

To encourage the widespread diffusion of greenery at home, smart, green and low-cost systems and components have been defined for the sustainable production (without pesticides) of horticultural products with innovative systems (using *olla* and ozone) to be inserted on balconies and terraces.

Finally, the applications of these systems to transform buildings into outdoor vertical farms are evaluated.

KEYWORDS

Green facades; vertical farm; sub irrigation system; ozone; IoT for balcony cultivation

INTRODUCTION

The global urban population is increasing (up to 9.8 billion people by 2050) and is more than half of the total world's population (55% according to United Nations data). This has contributed to accelerate land use for cities even to the detriment of agricultural and forest land.

The urbanization process has removed most people from food production and made them dependent on food imported from increasingly far territories [1].

This has potential consequences for food security, greenhouse gas emissions and environmental sustainability. Moreover, the recent pandemic has highlighted the need to make cities more and more resilience. Resilience in cities is a complex concept and indicates the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to transform quickly systems that limit current or future adaptive capacity [2, 3]. In short, it can be defined as the ability of an urban system to quickly transform systems to cope with the new condition. Regarding food, cities have to become more self-sufficient [4] and transform balconies and terraces into gardens useful for horticulture. Indeed, urban food production can have other advantages in relation to the mitigation of the bad quality of air in cities. Since food chain is changed, it could reduce net greenhouse gas emissions because of its potential to produce food with lower intensity of transportation energy use and packaging, and greater carbon sequestration [5].

Therefore, urban food production can be an important component of urban ecosystems able to mitigate the climate and improve the environment quality of cities but it can be positive, at the same time, for physical, psychological and social health [6, 7].

The research focuses on farm to fork productive urban green that can improve the resilience of cities to disruptive events such as heatwaves [8, 9], heavy rains and pandemics. To encourage the widespread diffusion of greenery at home, smart, green and low-cost systems and components have been defined for the sustainable production (without pesticides) of horticultural products with innovative systems to be inserted on balconies, terraces and facades.

METHOD AND SPERIMENTAL SETUP

Concerning city resilience, it is necessary to research new effective low-cost solutions of vegetable greenery at building level to use on balconies, terraces and facades.

In this perspective, great help can be given by the application of IoT also in urban agriculture. Agricultural technologies are rapidly evolving towards Agriculture 4.0 that includes precision farming, IoT, autonomous systems that allow saving water and energy, increasing the growth of plants and reducing the parasites.

The agriculture 4.0 can assure the conditions for the well-being of the plants and thus the right production of chlorophyll. The goal is to increase chlorophyll as it produces energy and oxygen and makes crops healthier, lusher. Indeed, chlorophyll is natural bactericide.



Figure 1: Main conditions of well-being of the plants

To enhance chlorophyll, it is necessary to act above all on the “water” element used as a vector to supply oxygen and minerals (Fig. 1), at the same time, regulating its use by means of sub-irrigation techniques that above all reduce waste. Hence, plant well-being is essential for horticultural production and reduction of urban heat island effects. Otherwise, plants could not have a positive effect in the mitigation of high temperature. If they are not sufficiently watered, they close the leaf stomata and, thus, the cooling evaporation process is reduced [10, 11].

Therefore, the idea is the application of three techniques in relation to water need (Fig. 2), so it combines the use of clay pots (*ollae*), ozone and IoT to increase the well-being of plants.

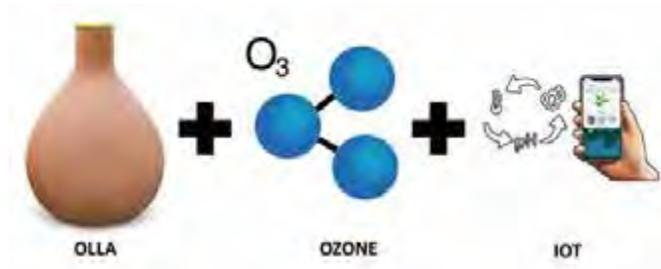


Figure 2: Application of three techniques

Ancient technique of sub irrigation: the use of *ollae*

In order to obtain optimal agricultural production, it is above all necessary to seek adequate solutions to improve efficiency in the use of water, especially in those parts of the world that have limited water resources. In fact, it has been calculated that only 10/30% of what is supplied is actually used by the root system, the remaining part is dispersed by: evaporation (30/50%), weeds (10/20%), deep percolation (5/10%), slipping (10/30%) (Fig. 3).

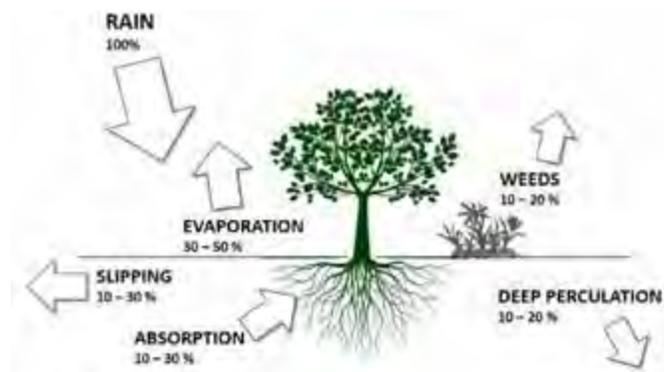


Figure 3: Waste of water

Therefore, it seemed appropriate to focus primarily on low-cost techniques that can guarantee an ideal water supply for the plant. An ancient irrigation technique appeared to be more suitable for this purpose [12, 13]. This is still used in the warm countries of the Mediterranean area, where a rudimentary but extremely effective method of underground micro irrigation is used by exploiting ancient knowledge handed down for generations [14]. It adopts simple ampoules in raw (unglazed) fired clay called *ollae*.



Figure 4: Advantages of olla

The *olla* (Fig. 4) is a common pot from the Roman age with or without a lid and mostly equipped with handles. It was used as a container with a dual function, both domestic and funeral. It is characterized by its rounded shape. They were produced locally with various types of dough (travertine, terracotta, glass, alabaster, marble, etc.) and were found both in settlements inside houses and in funerary areas in the cremation burials of the early Roman imperial age, used in this case as urns to contain the ashes of cremated people. Some of these containers were made of raw clay mixed with marble powder to make the dough more resistant to cooking.

These large pots, also used in ancient times for the transport and storage of oil or olives, were buried almost entirely in the ground, filling them with water and thus transforming them into considerable water reserves for the plants. They exploit the transpiration capacity of terracotta, which provides controlled irrigation, from the capillary flow to the surrounding root system. The *olla* is an ancient technique of sub irrigation practiced since the ancient Romans period and still in use in Iran, India, Pakistan, Egypt and Latin America [15].

The functioning of the pots allows you to provide the necessary water that the plant requires by moistening an area equal to about half the diameter of the olla. In this way, since the soil is not saturated, the surrounding environment created is very healthy for the roots of the plants, so much so that they themselves form a mat around the olla.

In the past, it was very clear that a plant needed to provide the necessary amount of water without exceeding both in defect and in excess. With this simple technique, a very efficient sub-irrigation system is created where the plants absorb the right amount of water, growing luxuriantly outwards on the mainland, efficiently using both space and water, significantly reducing its consumption.

The constant water supply of the underground clay pots improves germination, increases crop growth, accelerates maturity, reduces disease and increases yield, resulting in less weeds and less fertilizer use, even in places with very high temperatures, low humidity and drying winds. They can also be effective on sandy or gravelly soils that drain very quickly and using salt or alkaline water.

This system is well suited to vegetable gardens but above all to pots on the terrace or on balconies:

The main advantages of using *ollae* are: water reduction up to 70%, water filtering (e.g. the brackish one), efficiency, acting directly on the roots, reduction of evaporation, reduction of weed growth, practicality in the realization, greater soil aereosity, reduction of fertilizer consumption.

While it is a simple technique and full of advantages, there are limitations to sub-irrigation with clay pot.

It does not consider the appearance of pathogens, which, although limited, are not eliminated. The plant in these conditions, while growing luxuriantly, is however subject to an attack by parasites. For this reason, this technique needed to be accompanied by a new one to make up for these limitations.

Benefits of ozone use

Ozone is an essential gas for life on earth, allowing the absorption of dangerous ultraviolet light from the sun. The ozone layer in the stratosphere protects from the harmful action of ultraviolet rays. In addition to the filtering power, its judicious use consists in a transient mediation for many biological responses favouring a therapeutic action without any toxic effect, indeed, behaving as a real drug. In fact, its undisputed disinfectant action favours the treatment of many diseases of viral, bacterial and fungal origin thanks to an effect of strengthening the immune system.

Ozone derives from the Greek word “ozein”, which means “that smells”. It was discovered by chance in 1785 by Christian F. Schönbein while he was conducting some experiments, noticing the creation of a strange and acrid smell. After about sixty years (in 1839) it was thanks to another chemist, the German Christian Friedrich Schönbein who conducted similar experiments and gave it the name of “ozone”.

The chemical formulation O_3 , which we know today, was determined only in 1865 by other chemists that through experiments understood positive and negative aspects deriving from the great oxidizing power of this molecule.

Ozone is generated from diatomic oxygen molecules (O_2) in proximity of electric discharges, sparks and lightning, according to the following reaction: $3O_2 \rightarrow 2O_3$.

Since it is not a stable gas in the long term, it cannot be produced and sold in cylinders like other industrial gases. Therefore, it is generally prepared at the time of use through devices called ozonizers that convert pure oxygen or oxygen present in the air into ozone through electrical discharges [15].

Since this reaction is endothermic, it requires the absorption of a certain amount of energy, equal to about 69000 calories/mole.

There are different ways to produce ozone: by corona effect (Fig. 5), with UV lamps and by electrolysis.

Among these, the corona effect has proved to be the most convenient, as it is particularly efficient, and of which several variants have been developed.



Figure 5: Corona effect ozone generator

Basically, corona discharge ozonators consist of two concentric electrodes separated by a gap of a few tenths of a millimetre (0.8-1.5 mm), in which air or pure oxygen flows. A potential difference ranging from 7 to 30 kV is applied between the electrodes, with a frequency from 50 Hz to over 1 kHz. The innermost electrode is made of metal, while the outer electrode consists of a conductive metal wire that externally surrounds a tube made of dielectric material generally Pyrex, or ceramic. The internal electrode is connected to the medium/high voltage generator, while the external electrode is connected to ground.

Ozone can be produced from air or pure oxygen. Using air, ozone concentrations of 6% (w/w) are reached, while using pure oxygen, concentrations of 20% (w/w) are reached.

There are in production different ozone generators built using cells based on the corona effect such as: wide cavity, cold discharge Siemens type with very small cavity, metal mesh electrode and fine wire electrode.

Regarding Ozone, it is an unstable gas. With the passage of time it returns to lose the extra atom returning oxygen. Therefore, it is not possible to store it in cylinders and must be produced on site.

The main properties and advantages of use of Ozone in agriculture are [16, 17, 18]:

- High oxidizing power,
- Contrast of infections, parasites and fungi,
- Strengthening power,
- Respect for environment and living beings,
- Greater crop health,
- Strengthening of the immune defences of plants,
- Absence of residues,
- Authorization for organic farming,
- Repellent effect against vectors.

The use of ozone in agriculture is very important but the quantity must be moderate and studied according to the needs of the type of cultivation [19, 20]. It increases the chlorophyll but the resistance of ozone in the water depend on the temperature, as you can see in the table I. It can be some days for cold temperatures and only hours for warm temperature and minute for very hot temperature.

Table I: Resistance of ozone in water based on temperature [21]

| Temperature | Days | Hours | Minutes |
|-------------|------|-------|---------|
| 40 ° C | 0 | 0 | 32 |
| 35 ° C | 0 | 1 | 5 |
| 30 ° C | 0 | 2 | 12 |
| 25 ° C | 0 | 4 | 32 |
| 20 ° C | 0 | 10 | 0 |
| 15 ° C | 0 | 22 | 9 |
| 10 ° C | 2 | 2 | 0 |
| 5 ° C | 4 | 22 | 0 |
| 0 ° C | 11 | 22 | 0 |

The Internet of Things (IoT)

The Internet of Things (IoT) is one of the most promising scientific fields of the last decade and its spreading is enforced by the large number of smart device available on the market.

Nevertheless, IoT represents a new paradigm for connections: it is difficult to think that thousands of new device could be connected every day.

The diffusion of IoT and other smart devices, combined with the digitalization of the processes in the agricultural sector, is transforming it into a smart one, producing more with less, and working with more efficient use of natural resources, more sustainable activity, and also more transparent to the customers.

For many authors such as Rose and Chilvers [22] it is possible to talk about the fourth global agro-tech revolution, Agriculture 4.0 [23].

The IoT is rapidly becoming an integral part of our life as far as multiple industries life. It is expected to see the number of IoT connected devices explosively grows and will reach hundreds of billions during the next few years. The IoT refers to the inter connection and exchange of data among devices/sensors. Currently, with the explosive growth of the IoT technologies, an increasing number of practical applications can be found in many fields including security, asset tracking, agriculture, smart metering, smart cities and smart home. In each of these areas, the use of a common (IP-oriented) communication protocol stack allows the development of innovative applications. A sensor can be defined as a device that generates an electronic signal from a physical condition or event. At the same time, it is possible to define as network a system able to convey information to a remote site through a switching infrastructure. Furthermore, wireless networking technologies can provide from personal to wide area coverage with speed from few kbps (e.g., LoRaWAN) to 1 Gbps (e.g., 5G).

The first thing to point out is referred to the fact that all these new sensors will be deployed with some wireless technology rather than a wired medium. This is because the sensor network is often designed to be geographically extended [24]. An example could be a smart city with CO₂ sensors in order to sense smog: all these sensors are spread all around the city and send their data through some wireless technology, moreover they could be inserted on balconies, terraces and facades.

Experimental setups for a green balcony

In order to verify the efficiency of the proposed method, an experimental campaign was carry out comparing and combining the use of traditional and innovative techniques. Thus, different solutions for plant development were identified to be inserted on balconies and terraces according to the criterion of low cost. Therefore, for some setups, common unglazed terracotta pots were used, joined together with silicone adhesive to create watertight containers very similar to *ollae*, buried about 10 cm below the earth's surface (Fig. 6). These assembled pots were filled with natural water or water treated with a low quantity of ozone (0.5 gr/h for 15 minutes on 5 litres of water).



Figure 6. Assembled ollae - a) preparation; b) assembly; c) positioning; d) connection; e) underground.

The water ozonation process for these experiments was created using a system built for this purpose. It consists of an insulated box with a small control unit installed on the lid. This contains a small ozone producer of 0.5 g/h, and two small pneumatic membrane pumps controlled by a low-cost control unit for WiFi-based IoT applications (Arduino MKR WiFi 1010 board with WiFi capability that enables to build IoT application).

The presence of the two pumps is due to the need to be able to develop two separate circuits: the former to circulate the ozonated water inside the underground clay pots and the latter to push the ozonated water with a certain pressure towards another surface irrigation circuit consisting of atomising nozzles (nebulisers). These two circuits can be used independently or in combination. The inserted nebulizers are able to deliver a uniform water flow with a wide range of action, in order to affect the largest possible surface of the leaf apparatus.

The common element of these installations was the use of large PVC pots, 1 m long and 40 cm wide and high placed one after the other on a west-facing balcony overlooking a green area.

These large pots were all filled with universal potting soil and, using special sensors connected to the monitoring unit, the necessary parameters such as pH and humidity were measured at 30-minute intervals to determine the effective development of the plants.

Therefore, five different experimental setups were defined to compare the different solutions (Fig. 7.a) and monitor plant growth:

1. Without *ollae*, Nebulized Ozonized Water (NOW)
2. *Ollae* with Ozonized Water + Nebulized Ozonized Water (OOW-NOW)
3. *Ollae* with Ozonized Water (OOW)
4. *Ollae* with normal Water (OW)
5. Without *ollae*, traditional Watering (W)

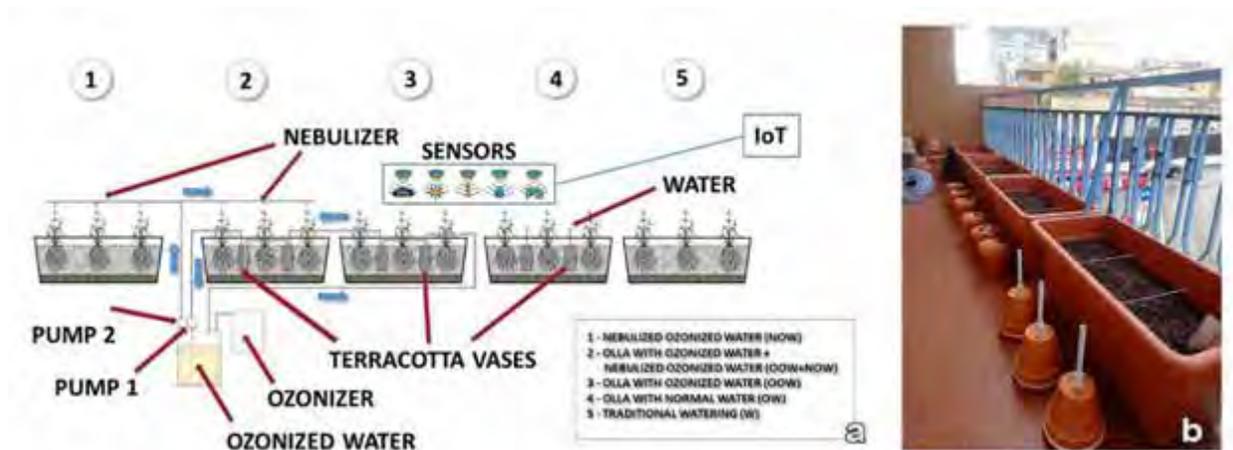


Figure 7. Experimentation on balcony - a) scheme of setups b) preparation

The Fig. 7.b and Fig. 8.b show the photos of the installation on the balcony concerning the ongoing experiment.

The programming implemented in the first experimental phase was to start a series of treatment cycles for three of the five setup, with the interval depending on the season. These range from one or two treatments within 24 hours in winter to 5 or 6 treatments in summer (Fig. 8.a)

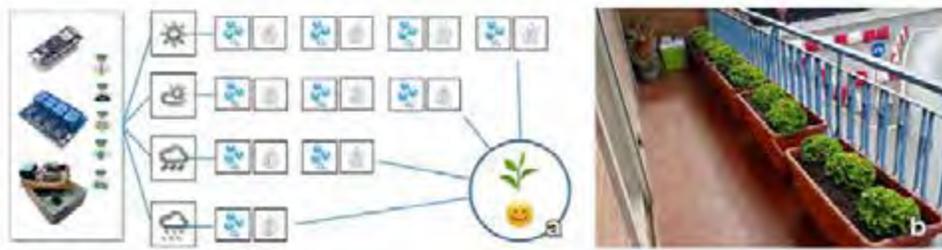


Figure 8. Possible experimentation scenarios - a) scheme b) plants growing

Each cycle is characterised by an initial period (15 minutes) of ozonation of the water contained in the box. At the 12th minute, the first pump is started for 3 minutes to circulate the water in the *ollae*, while the second pump for surface delivery is activated at the 14th minute for a duration of 20 seconds.

Each setup is monitored by IOT sensors in order to check humidity and pH (Fig. 9).



Figure 9. Plant health monitoring app

It is also proposed a system for facades that is very similar to the one used on the balcony where, however, coconut fibers is used to lighten the weight, and small coupled terracotta pots, connected together by a closed loop where ozonized water can circulate. For the facade, it is possible to use the channel for hydroponic.

The Fig.10 shows an example of installation on railings or on the wall of the balconies.

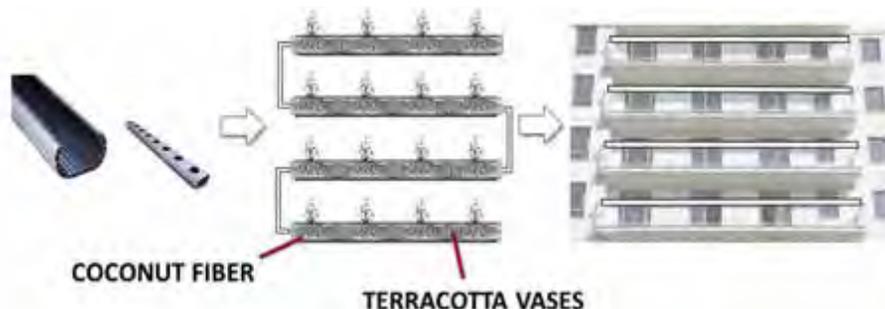


Figure 10. Possible installation on railings or on the wall of the balconies

RESULTS AND DISCUSSION

The comparison of the first results in relation to the different configurations and scenarios for lettuce, is showing that OOW-NOW- setup 2 (underground *ollae* crossed with ozonized water + nebulized ozonized water) is the most effective solution for the well being of plants.

However, this solution must be considered an increase in costs (10-20%), which depends on the double use of underground devices connected to each other and the external nebulization system to be installed on the surface. It should also be considered the greater difficulty to realize such a system and its not easy application.

However, through OOW-NOW- setup 2, a double corroborating action is provided to the plant, which acts both on the leaf apparatus and on the root system.

Ozone is supplied to the plants through ozonized water with its bactericidal, fungicidal and oxygenating action in two ways: it is nebulized outside on the leaves by atomizers and, at the same time, it is gradually transferred to the soil by the *ollae* through an osmotic effect.

A double beneficial action is guaranteed to the plants, providing them with the ideal conditions for their development and accelerating their time.

Alternatively, in order to reduce costs, a good compromise could be to adopt OOW - setup 3 that provides only buried pots crossed by ozonized water.

This solution partially guarantees the beneficial effects of OOW-NOW- setup 2, but considerably reduces the consumption of water, since the nebulization of water is not used. Although nebulization provides several invigorating benefits (including insect repellent), it causes higher water consumption due to evaporation and dispersion of particles into the air.

Applications of these low-cost smart systems could help turn buildings into more effective outdoor vertical farms, which make cities more resilient to disruptive events.

The app, which is under development, allows data analysis at neighbourhood- and city-level as support for green policies.

This is an ongoing research because it is necessary a long period of observation during the year and different seasons in order to test the five scenarios.

Anyway, the first results of two months are promising as table II and table III show in the different configurations.

Table II: consumption and average values per week (autumn period)

| | NOW | OOW-NOW | OOW | OW | W |
|-------------------------------|------|---------|------|--------|-------|
| Water consumption | 4 l | 6 l | 2 l | 1,5 l | 4 l |
| Energy consumption | 10 W | 20.5 W | 15 W | 0 W | 0 W |
| Human time | 2 m. | 2 m. | 2 m. | 8 m. | 14 m. |
| Visual quality | 8/10 | 9/10 | 8/10 | 7/10 | 6/10 |
| Quantity of production | 8/10 | 8.5/10 | 8/10 | 7.5/10 | 7/10 |
| pH | 7.0 | 7.2 | 6.9 | 6.8 | 6.3 |
| Humidity | 79% | 82% | 78% | 81% | 78% |

Table III: costs and difficulties (autumn period)

| | NOW | OOW-NOW | OOW | OW | W |
|---------------------------------|------|---------|------|------|------|
| Cost installation (cad.) | 60 € | 100 € | 80 € | 40 € | 25 € |
| Realization difficulty | 5/10 | 9/10 | 6/10 | 4/10 | 1/10 |

CONCLUSIONS

The study proposes intelligent and economical solutions that, above all, reduce the human contribution to the care of plants to a minimum. In this way, it is possible to transform easily cities into vertical farms, orienting towards multi-objectives: reduction of carbon dioxide emissions, production of oxygen and horticultural products that we can define “0 meter” because they are produced on balconies and facades, i.e. in close proximity conditions. Other aspects that should not be overlooked are certainly the psychological advantages and the cultural recovery of the direct approach to nature, which new generations are losing completely due to an ever-greater concentration of the population in the cities with respect to agricultural areas. These proposed solutions, which are low-cost and efficient both for water consumption and for the production of agricultural products, will represent a valid aid to make future citizens acquire the awareness of the profound value of an agricultural product grown directly in their own habitat rather than buy it from large retailers.

However further studies are necessary to test the maximum threshold amount and concentration of ozone in the water to maximize the positive effects and avoid possible negative effects in different seasons.

ACKNOWLEDGEMENT

We are grateful to leaf s.r.l. (Bari, Italy) for collaboration.

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MAKING A CASE FOR URBAN SOLAR PV ENERGY GENERATION

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ABSTRACT

Broad use of photovoltaic (PV) energy for individual home owners is constrained by perceived high costs, complexity, utility net-metering limitations, and perceived waste in over-generation. This paper proposes a simple alternative application of PV generation in an urban setting that addresses some of these challenges and that may open a path to adoption.

The concept incorporates a system configuration that is small scale and designed to match the energy generation during summer months to expected demand, with on-site battery storage to balance daily requirements. The intent is to make use of all the PV energy produced when it is available and to make use of grid energy when it is not. The system would be independent of the grid and net-metering would not be considered. The system would be intended to maximize the use of the PV energy generation with no waste.

This concept is applied to an urban setting in Vancouver Canada characterized by a perceived cheap green energy mix and a mature built environment.

A system is sized by assuming an average household demand with expected generation based on actual PV arrays in the Vancouver region. Costs are assessed for commercial installation. Requirements for switching between PV and grid energy is defined. Energy cost is estimated over an assumed system lifetime of 25 years and this is compared to the current rates. The effectiveness of the concept to provide broad energy generation is defined in terms of the number of such installations that would be required to replace the energy produced by a new currently being considered hydro generating station and comparing the costs involve

KEYWORDS

INTRODUCTION

The adoption of energy generation from photovoltaics (PV) is increasing but still remains low. Estimates are that PV accounts for about 9% of installed generation capacity globally [1]. This low number is often used by the fossil fuel industry to justify continued development. The world needs to improve PV adoption rates to start to counter this narrative.

The United Nations reports that, globally, 78% of all energy is consumed in cities [2]. Similar numbers would be expected for that portion of the energy that is electricity demand.

This paper proposes a simplified concept for solar PV energy generation in an urban environment, specifically the urban environment of Vancouver Canada, and assesses that concept for viability relative to the current electricity rate structure and to a new hydroelectric project currently underway. The objective is to offer a potential path to increased deployment of PV generally.

Background to the analysis is provided in a discussion of the challenges to PV adoption both from a general sense and more specifically with respect of PV in residential settings in Vancouver.

The idea behind the concept, its characteristics and expected performance are defined together with the average residential electricity demand in Vancouver and current rate structure. The cost for the system is estimated and a levelized cost of energy is calculated over its useful life.

Comparisons are made between energy costs for the proposed PV concept and the actual costs currently paid by consumers as well as to the expected energy costs for a new large-scale hydroelectric project.

Finally, the potential for broad application of the concept is discussed.

BACKGROUND

Challenges to PV Adoptions

We first look at challenges and perceived barriers to the adoption of PV.

Studies have shown, [3][4], that people have concerns related to: complexity and a perceived lack of technical awareness, to costs, and to efficiency (waste) of PV systems.

We contend that complexity comes not so much from the standpoint of technology; the technology is mature and relatively simple. Complexity is more related to how to incorporate PV energy into a very complex overlying electricity grid. The grid is based on a market-based model with disparate generation costs and generation capacity based on demand peaks. The grid is based on a paradigm of large central dispatchable generating sources, one-way information flow and with well understood control strategies. Renewable energy is problematic for such a system. Renewable energy, particularly PV, is seen by the grid as drops in demand that are unpredictable day-to-day and hour-to-hour.

It is possible to change the way the grid operates and to turn it into a *smart* grid that includes two-way information flow and allows for control of loads. Research is ongoing into this next-generation grid. At present the tendency for grid operators is to avoid the problem by placing limits on the amount of PV that will be allowed to be incorporated into the grid and by controlling net-metering. The public utility in British Columbia recently started to scale back their net-metering program [5]. And while there is not a specific defined limit to the percentage of renewable energy on the grid it is understood that such a limit exists.

There are institutional barriers related to permitting requirements. PV on roofs or stand-alone arrays are still a relatively new thing and planners and permit authorities tend to treat PV installations as novel and requiring special consideration. These barriers are likely to become less of an issue as more installations come online and standardization of requirements become the norm.

There is still a general perception that energy from PV is going to be much more costly than energy from the utility. PV ends up competing with a perceived and somewhat artificial *low* cost of grid energy. It is in the utilities interest to have rates appear low. This keeps customers happy and mollifies regulators. All this leads to a rate structure that implies low energy rates while hiding total costs.

Efficiency is of interest to everyone. No one wants to think that the money invested in a PV system results in unusable (wasted) energy generation.

The Vancouver Framework

Vancouver is an urban area located on the west coast of Canada within the province of British Columbia (BC). British Columbia is the third largest province both by population and by area. It is bounded by the Pacific Ocean on the west and the Rocky Mountains on the east.

Greater Vancouver is BC's largest metropolitan region and home to over half of the total population for the province. Greater Vancouver encompasses the largest electricity consumption.

Vancouver's electrical energy is supplied from the provincial grid. The grid is owned and operated by a public utility; BC Hydro. BC Hydro owns and operates a series of generating stations. These are primarily large-scale hydroelectric stations on large river systems

The system currently has 12.1 GW of generating capacity with 80% supplied from 5 large dams on two major river watersheds in the interior of the province; the Peace River in the north and the Columbia River in the east. The generating stations are located significant distances from the major consumers in urban areas particularly, Greater Vancouver, so the system also incorporates very long high-voltage transmission lines.

The resulting electrical energy mix for Vancouver is about 93% from hydroelectric generation.

Many people consider Vancouver's electricity supply to be renewable *green* energy. This includes many politicians. The City of Vancouver has had an initiative in place since 2009, named the *Greenest City Action Plan* [6] which had as its goal that of being the *greenest* city in the world by 2020. A major piece of this initiative, and the prime motivation for considering it to be achievable, has been the plan to electrify transportation and home heating utilizing the abundance of *renewable* electricity.

Many other people, the authors included, see problematic aspects of large disruptive hydroelectric facilities; Hydroelectric dams destroy natural habitats. The Columbia river historically held one of the largest natural pacific salmon populations in the world. This is no longer the case. Hydroelectric dams disrupt peoples lives and livelihoods. The building of one series of dams on the Columbia River in the 1950s required the *relocation* of two entire communities. Dams on the Peace River have flooded prime arable land and forced working farms to be shut down. Dams infringe upon indigenous people's rights.

The sense that Vancouver's electricity supply is *green* and *renewable* persists.

In addition to being considered green, Vancouver's electricity is perceived to be *cheap*. British Columbia's average cost of electricity is the third lowest in Canada. The published *tier1* residential rate is 0.094 CAD/kWh. However, this low rate is mostly a marketing mechanism and does not convey the complete picture. There are other aspects of the rate structure that modify the actual cost of energy paid by consumers.

Vancouver consists of, primarily, fully detached homes on small lots. Most lots are 7.5m to 10 m in width. Most are older homes, built 50 to 70 years ago, built before standards of energy efficiency were considered. There is little use of energy conservation measures, likely a by-product of the perceptions of cheap, green energy.

Vancouver offers a unique set of challenges to the adoption of PV.

ANALYSIS

Concept

The proposed application of PV is intended to address the specific challenges of complexity, cost, and waste through over generation.

As discussed above, the technological aspects of PV installations are not all that complex. Complexity in PV systems flows down from how the grid operates particularly through restrictions and limitations on how energy can be produced. To avoid this complexity the proposed concept is to be kept completely independent of the grid. The proposed application of PV is not interconnected to the grid.

To minimize costs, the system is conceived to be small scale. There is no expectation to replace all the electricity needs throughout the year (such as for a full off-grid system or a net metered system). The system is roughly sized to provide energy needs for a typical summer day when the generation capability of the array is at its maximum. The proposed system is small scale.

In keeping with the philosophy of avoiding issues with grid interconnection, the proposed concept is a *dual* system. There is no energy flow between the PV and the grid nor is grid energy used to charge the system's battery storage component. Electricity demand is met by PV when PV is available. When PV is not available the energy demand is met from the grid. The proposed application of PV is bimodal.

The intent of the concept is to maximize the use of the solar energy generated. All PV energy generated for any day of the year is used. The proposed system minimizes waste.

Demand and Rate Structure

The average BC Hydro residential customer consumes about 9700 kWh annually or about 26 kWh per day [7]. There is typically little variance in daily average consumption throughout the year. Vancouver has very little need for air conditioning and most homes are heated using natural gas. Therefore, the primary difference between summer and winter demand is in the amount of lighting used. As previously stated, there is a general underutilization of energy conservation measures.

As previously stated, the posted tariff, the *tier 1* residential rate, is 0.094 CAD/kWh. This rate is considerably lower than most other areas in the world. Also stated was the fact that this is not the whole story for electricity costs in British Columbia. The *tier 2* residential rate is 55% higher at 0.146 CAD/kWh. This rate is applied when the daily consumption, averaged over a billing period, rises above a threshold value. The current threshold is about 22 kWh/day or slightly lower than the daily consumption for the average residential customer. In addition to these rates there is a *basic* charge paid by all customers connected to the grid. This is a service access fee and amounts to 0.208 CAD/day.

The resulting effective electricity rate is, therefore, dependent on how much energy is consumed in any billing period. The actual effective rate paid by customers ranges from 0.11 to over 0.15 CAD/kWh. The low end of this range is paid by customers whose consumption is near to the daily threshold limit. Customers who either consume more than this or less than this pay a higher effective rate. As an example, the authors who are at the low end of consumption, paid between 0.148 and 0.161 CAD/kWh for the last 4 billing periods.

It should be noted that these numbers are based on current electricity rates. These include a recent 6% rate increase applied in 2020 [8]. There are additional rate increases scheduled to come into force amounting to about 8% by 2024.

PV Generating Capabilities in the Vancouver Area

We now look at what would be achievable from a PV system in the Vancouver area.

Published data for the capacity factor for PV systems ranges between 0.1 and 0.25 [9]. This low capacity factor is primarily due to intermittency of generation, to the fact that generation only occurs during daytime hours, and that there is waste in generation from periods when demand and generation do not coincide.

Vancouver experiences significant rainy weather in winter and in parts of spring and autumn but with generally dry and clear summers. This results in a wide disparity in generating capability throughout the year. For this reason, we use actual generating data from four Vancouver area PV arrays instead of using published capacity factors. Two of these arrays are part of a research facility in an academic setting. The other two are part of a *solar garden* project owned by a community within greater Vancouver. Data from these arrays are available for up to four years.

From this data we find a specific annual generation capability of up to 1100 kWh per kW of array per year (kWh/kW/year). This equates to a capacity factor of 0.125. Further we find a maximum specific daily generation capability of about 6.5 kWh/kW/day in the summer. To provide our average 26 kWh demand would require an array capacity of about 4 kW.

System Configuration

Current technology for PV panels [10] indicate that 335 W panels have dimensions of 1.7m by 1m. A 4kW array would require 12 such panels which would measure roughly 4m by 5m or 20 square meters in area.

Lithium-ion battery storage is considered to provide daily balance requirements and properly conditioned power. Commercial off-the-shelf storage systems are available fully designed to work with PV. Typical systems come in roughly 10 kWh capacity which is felt to be adequate to provide the daily balance requirements.

Additional equipment requirements include charge controller and inverter. Many inverter topologies and control strategies are available that ensure good power quality [11]. Also required is a two-way switch to select between PV and grid power and to prevent accidental energizing of the grid from the solar system.

This is not a complicated system. It is essentially an undersized off-grid system that runs parallel to grid energy supply. There are many examples of mature off-grid system configurations. There is no leap in innovation required to procure and implement such a system. Such a system is technically viable.

System Cost

Costs for PV panels, equipment and installation have dropped substantially over last several decades [12]. Similar trends are to be seen in installation costs.

Current online commercial offers for installed PV systems for British Columbia range from 2.5 to 2.7 CAD/W [13]. Costs are continuing to drop and as more PV is installed lower costs can be expected. It should also be noted that further reductions in costs can be achieved by homeowner undertaking some of the installation labour that does not require certified electrical work.

Soft costs include design services and permitting. System designs are now fully mature so that specific design services should not be required. Mounting systems are standardized and systems come in the form of kits with all required racks and mounting hardware. The City of Vancouver has instituted a low fixed cost permitting scheme to encourage adoption [14]. Such soft costs are not considered significant for this analysis.

Similar to PV systems, the costs of li-ion battery storage have dropped precipitously. A recent MIT study [15] indicates that li-ion battery technology costs have dropped 97% since 1991. A recent article [16] projects that prices could drop by a further 80% over the coming decade.

A recent online commercial offer indicates that a 9.8 kWh battery system can be purchased for about CAD 5500. This is for an off-the-shelf system that is fully designed to operate with a PV system and comes with full warranties

The Canadian federal government currently offers grants as incentive to install renewable energy. These grants are for up to CAD 1000 per kilowatt of installed capacity to a maximum of CAD 5000.

With these numbers the total cost for the system can be estimated:

- Panels and required supporting equipment, 4x2700, CAD 10800,
- Battery system, CAD 5500,
- Incentive, CAD -4000,
- Net Cost installed, CAD 12300,

These numbers are current costs and do not include any of the anticipated cost reductions.

Levelized Cost of Energy for PV

The typical warranty period for panels and equipment is 25 years and this is felt to be a reasonable useful life for a PV system. In reality the system will likely continue to generate electricity beyond this time frame

We have seen that the specific annual generation based on actual data from Vancouver arrays is 1100 kWh/kW of array. For our 4 kW array the annual generation can be expected to be 4400 kWh or roughly 45% of the average annual consumption.

Gross energy generated over the defined lifespan of 25 years amounts to 110000 kWh. Lost energy due to panel degradation has been estimated by the National Renewable Energy Laboratory (NREL) in the United States, as 0.5% per year. For our system this amounts to 6875 kWh resulting in a net energy generation over the defined lifespan of 130125 kWh.

Table I summarizes the levelized cost of energy for our PV system.

Table I: Levelized Cost of Energy for PV System

| | | |
|------------------------------|--------|---------|
| System Cost | 12300 | CAD |
| Array Capacity | 4 | kW |
| Specific Annual Generation | 1100 | kWh/kW |
| Annual Generation | 4400 | kWh |
| Lifespan (typical warrantee) | 25 | Years |
| Lifetime Generation | 110000 | kWh |
| Loss to Degradation | 6875 | kWh |
| Net lifetime Generation | 103125 | kWh |
| Levelized Cost of Energy | 0.119 | CAD/kWh |

The resulting cost of energy for the system is 0.119 CAD/kWh. This compares favourably to the range of current electricity rates, 0.11 to 0.15 CAD/kWh, stated earlier. It should be noted again that the lowest end of this range is for a small subset of customers, those with consumption just at the threshold between *tier 1* and *tier 2* rates. For most people the electricity rate falls in the middle towards the high end of this range. It should also be noted also that these are based on the current rates and that rate increases are certain.

The key point is that costs for electricity from PV are similar and in certain conditions better than current electricity rates. They are not two or three times greater, as may be assumed by many people.

Comparison to New Hydro

Now let us look at how this all compares to electricity generation for the business-as-usual case, new large-scale hydro. A new hydroelectric generating station is currently under construction in BC that will form a useful counter point to PV.

The *Site C* hydroelectric project consists of a new dam with a 1100 MW generating station on the Peace river 800 km north of Vancouver. This will be the third dam/generating station on the river.

The latest estimated capital cost budget for this project is 16 billion CAD [17]. This is twice the original budget and there are indications that by the time it is completed the costs will have escalated further. The new station is expected to be commissioned in 2025.

The published average values for the capacity factor for hydro ranges between 35% and 40%. For our analysis we use actual generation data provided by the utility. BC Hydro publishes statistics every year with respect to generation capacity and electricity sold. For 2020, generation capacity was 12.1 GW and the energy sold was 52113 GWh. This works out to an actual capacity factor for stations on the grid to be 0.49, slightly better than the published averages. For our analysis we use a capacity factor of 0.5.

For the assumed useful life we use 25 years. This may seem low for a hydroelectric project but there is some justification. All the main dams in the province are on rivers that drain from the Rocky Mountains and rely on accumulated snow pack to regulate flows throughout the year. Studies indicate [18] continually dropping numbers for snow pack and for snow cover, due presumably to climate change impacts that include warmer winters. Along with reduced snow packs come changes to time frames for maximum stream flows which now occur earlier and are of shorter duration. There is also evidence that mountain glaciers are receding which will also have an impact on the stability of streamflows.

Societal *pushback* and loss of social license is also an issue. Public opinion is shifting about the *greenness* of large hydro for many of the reasons already stated. Public protests against the building of *Site C* continue.

It is the authors' opinion that 25 years from now none of the large hydro generating stations will be able to operate as they currently do.

Given these issues around large-scale hydro, 25 years seems an appropriate assumed generating life for a new hydro project and it is consistent with the life span assumed for PV in our analysis.

The expected lifetime energy from the new hydro facility amounts to about 120.45 million GWh

Table II summarizes the levelized cost of energy calculation for new hydro.

Table II: Levelized Cost of Energy for New Hydro

| | | |
|----------------------------------|----------------|---------|
| <i>Site C</i> Hydro Project Cost | 16,000,000,000 | CAD |
| Generation Capacity | 1100 | MW |
| Capacity Factor | 0.5 | |
| Life | 25 | Years |
| Lifetime Generation | 1.2045E+11 | kWh |
| Levelized Cost of Energy | 0.133 | CAD/kWh |

The resulting cost of energy for new hydro is 0.133 CAD/kWh. This can be considered a marginal cost for electricity produced using the current business-as-usual paradigm.

The cost lies within the middle of the range for the current rate structure. For the energy produced from this new dam to be financially viable it will likely require rate increases, and this is presumably the rationale underlying the projected rate increases that are planned.

The cost of energy for new hydro is higher than that for our PV system. New energy from PV compares favourably to this marginal cost for new energy from large hydro.

Again, it should be noted that capital costs for *Site C* are likely to further increase before any electricity is generated. Also, the cost calculation presented here is a simplified calculation that includes only capital costs and excludes cost that otherwise might be included such as: operation and maintenance costs, financing costs, and transmission costs (a reminder that the new generating station is 800 km from the customer base in Vancouver). The effect that these cost considerations may have are discussed in the following section.

DISCUSSION

Considerations with respect to Costing Assumptions

The cost calculation for new hydro has not included operation cost, maintenance costs, financing costs (which are likely to be significant), nor are transmission costs to get the power to the Greater Vancouver area included. Costs for new hydro have not accounted for likely projected budget increases. Comparisons have been made relative to current electricity rates and have not accounted for planned rate increases. The cost calculation for PV has not considered likely equipment and installation cost decreases.

Were such adjustments to cost to be considered it would likely to place PV in an even better light as a form of alternative energy generation.

Potential for Broader Application

The question remains of how many such PV installations would be required to provide the same amount of energy that the new hydro generating station would produce over its life. Dividing the total lifetime generation for *Site C* by the lifetime generation for our conceptual PV array we get a figure of 1,095,000 installations required. There are an estimated 750,000 detached homes in the greater Vancouver area. There are a further 340,000 detached homes in other sunny regions of the province.

Technically at least, it is feasible to replace *Site C* with local small-scale PV. And it should be noted that there are many other applications of PV, beyond the detached home, that would allow for similar cost-favourable expansion of PV capacity.

The tax burden would be significantly less since the PV systems would become homeowner or community assets and tax monies would only be needed for that portion of costs covered by government incentives. What you would get is a shift in paradigm favouring local energy generation where changes in electricity demand are more efficiently met.

This is just a Starting Point

Applications of the proposed concept would put simple, small-scale, low-cost PV systems in place. In the future arrays can be augmented towards higher generation potential.

One avenue would be 100% off-grid PV systems in conjunction with dedicated conservation measures to reduce the nominal 26 kWh daily demand. The authors' 2019 ECOCITIES paper [19], contends that a daily demand of just over 5 kWh is achievable without loss of comfort and convenience. Consumption reductions are possible through the use of LED lighting, phantom load reduction, the use of high efficiency appliances and electronics, energy recovery to reduce water heating loads and space-use efficiencies. The paper suggested that an array of only 5.5 kW would be required which is not much larger than the proposed system in the current analysis.

Another potential pathway is for neighbourhood level micro-grids. In this scenario multiple households in a neighbourhood would share generation and storage capacities with, possibly, a school or community center as a central anchor point to help to balance generation and loads for the entire micro grid.

Expansion of PV generation and storage capacities can be attained while avoiding the complexity of grid interconnection.

CONCLUSIONS

A simple small-scale low-cost concept for PV installations in a urban environment has been proposed. In addition to being low cost the concept is intended to address issues related to perceived complexity and to maximize the use of the solar energy generated. The concept as proposed is a bi-modal system allowing electrical loads to be serviced either by generated solar energy or by grid energy. The concept as proposed is not connected to the grid.

The concept has been assessed by applying it to the specific urban characteristics of Vancouver Canada. Vancouver is seen to hold unique challenges to adoption of PV including an energy mix that is perceived to be low cost and renewable as well as being a mature built environment.

A PV system has been conceived to meet the average electricity demand for a typical Vancouver household assuming summer generation capabilities. The system consists of a 4 kW PV array, 9.8 kWh of battery storage, inverter and charge control hardware and a switch functionality to allow select ion between PV energy and grid energy.

Costs for the system have been estimated and a levelized cost of energy has been calculated for the system's useful life. The cost of energy was seen to be favourably comparable to current electricity rates as well as to the marginal cost of energy for a new hydroelectric project.

The potential for broad application of the concept has been assessed by determining that it is, at least, technically feasible to replace the energy that would be generated by the new hydroelectric project with PV installations based on the proposed concept.

The analysis presented is conservative in nature.

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SUSTAINABLE SEDIMENT MANAGEMENT IN WATER INFRASTRUCTURES THROUGH THE INNOVATIVE “EJECTORS PLANT” TECHNOLOGY

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ABSTRACT

Preservation of a good navigability in harbours, ports and waterways is a challenging issue. Sediment is currently removed through maintenance dredging, but without being effective in keeping navigability over the time. This objective may be reached through a higher frequency of dredging operations, but would result in higher costs and complex authorization/permit procedures. Maintenance dredging also has considerable environmental impacts: dredging i) greatly modifies underwater habitats and resident flora and fauna, ii) resuspends sediments and contaminants, iii) impacts locally on greenhouse gas (GHG), pollutants and noise emissions.

The “ejectors plant” technology has been developed as a sustainable alternative to maintenance dredging and has been recently tested in two different applications in Italy. Both plants were monitored for more than one year to assess i) water depth, ii) energy consumption, iii) maintenance costs, iv) seabed features and species diversity, v) CO₂ emissions, vi) underwater noise impact. The minimum water depth required was guaranteed at the end of the monitoring period. Monitoring actions revealed that seabed features and species diversity were improved and that the impact on underwater noise was absent. Finally, an optimized ejectors plant, if fed by renewable power, could cut more than 80% of GHG emissions and guarantee near-zero pollutants emissions in comparison with traditional dredging.

The ejectors plant has the potential to be widely applied for the ordinary maintenance of water infrastructures. The paper explores the opportunity to integrate the technology with nature-based solutions and for the combined generation of renewable heating and cooling for buildings.

KEYWORDS

sediment management, ejectors, sustainable infrastructures, nature-based solutions, building heating and cooling

INTRODUCTION

The need to remove deposited material from water basins is a common feature shared by harbours, ports and waterways. The most widely used solution to remove sediment deposits is dredging. Dredging is a well-known and reliable technology. Nevertheless, in specific conditions (i.e. smaller marinas and channels), dredging in shallow water requires scaled technologies that are less productive and more expensive than common configuration. While dredging is able to restore the desired water depth, it is not without impact on sedimentation causes and therefore cannot guarantee avoiding sedimentation over time. Furthermore, dredging operations can often interfere with navigation and other nautical activities, and imply environmental impacts for the marine ecosystem [1], like modifying marine habitat related organisms and disturbing contaminants already present in the seabed. As a consequence, maintenance dredging operations often become too expensive and/or are not allowed by normative framework due to the related environmental impact.

New approaches have been developed over the years as alternative methods to dredging and a wide literature exists about innovative solutions to limit and/or solve sedimentation [1]. A promising solution alternative to maintenance dredging is the so-called “ejectors plant” technology. The ejector (see Fig. 1) is an open jet pump (i.e. without closed suction chamber and mixing throat) with a converging section instead of a diffuser and a series of nozzles positioned around the ejector. Each ejector is placed on the waterbed and transfers momentum from a high-speed primary water jet flow to a secondary flow that is a mixture of water and the surrounding sediment. The sediment-water mixture is then conveyed through a pipeline and discharged in an area where the sediment can be picked up again from the natural water current or where it is not an obstacle for navigation. For example, with a primary water feeding flowrate of ~ 27 m³/h, a working pressure of ~ 2.4 bar and a discharge pipeline characterised by 60 metres in length, each ejector is able to convey a peak sand flowrate at the discharge pipeline of about 2 m³/h (whole discharge flowrate is ~ 34 m³/h) and a water pump power consumption of about 3.5 kW [2]. Ejector performance changes as a function of i) discharge pipeline length and ii) sediment characteristics.

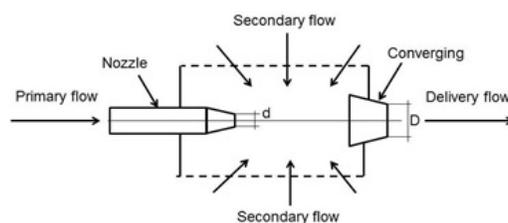


Figure 1. Schematization of ejector geometry and operation.

The main novelty of the ejectors plant is that it is designed and controlled to bypass the settling sediments, and not to remove them from the waterbed. This feature is important in authorisation and permit procedures, since the mass balance in the area where the ejectors are installed can be considered as zero, and therefore the ejectors plant operation is not equated to maintenance dredging. Moreover, the continuous operation of the plant reduces the environmental impact to near zero, since

the sediment management follows the rhythm of nature. The technology is reliable as, generally speaking, jet pumps have been applied for coastal application since the 1970s. Regarding the ejectors technology, it was developed and tested in 2001 by the University of Bologna and the start-up Plant Engineering Srl. In 2005, the first experimental plant [3] was realised and tested in the port of Riccione in Italy. In 2012, a second experimental plant [4,5] was implemented in Marina di Portoverde in Italy. Both installations were realised at harbour entrances and designed to handle sand. Recently, two further ejectors plant installations have been realized in Italy. A pilot installation was established in 2018 in Cattolica [6], where for the first time two ejectors were applied in the management of silt and clay sediments and installed in a river channel. The first demonstrative installation has been completed in 2019 in Cervia [2]. The 10-ejectors demo plant operated continuously from June 2019 to September 2020, thus achieving the objective of the LIFE MARINAPLAN PLUS project, which financed the realization and monitoring of performance and impacts produced for a minimum period of 15 months operation.

The paper briefly introduces the ejectors plant technology concept and the main results achieved in Cattolica and Cervia installations. Then, the paper aims to explore two different integrations of the ejectors plant: the first one is the combination with anti-sedimentation nature-based solutions, the second one is the production of renewable heat and cooling energy through reversible heat pumps for the building sectors. Both integrations aim to further reduce costs, thus maximizing the economic impact while strongly reducing the environmental impacts related to maintenance dredging.

TECHNO-ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF EJECTORS PLANT TECHNOLOGY

Techno-economic assessment

The pilot plant in Cattolica has been designed to feed with pressurized water up to two ejectors. Each ejector is fed by its own submersible pump. The water flowrate in each ejector feeding pipeline can be controlled by inverter. The water pressure at the pumps outlet is monitored by pressure transmitters. Power consumption is measured by an electric multimeter installed between the grid and the inverters. The pumps operation can be scheduled on an hourly base, while the plant operation can be remotely checked and modified. Instruments readings have a frequency of about one second, but data are saved only every five minutes in a local database that can be remotely accessible to limit the size of the data storage. The pumps are installed near the entrance of a towing basin, while the ejectors are located inside and outside the towing basin. The internal ejector has been numbered as ejector n°2, while the external ejector is the n°1. The electric panel has been installed very close to the pumps. Fig. 2 shows the position of pumps, ejectors, and electric panel. The position of the ejectors is approximate, since they were not fixed on the stream bed and during the 12 months of monitoring the ejectors, and in particular the ejectors n°2, were manually moved.



Figure 2. Location of ejectors plant in Cattolica [6].

After more than one year of operation monitoring [6], the pilot plant demonstrated to be effective in keeping constant the water depth in the towing basin. The pilot plant worked for 8475 hours and, based on the relation between bathymetries and operation regime, a mean power consumption of 5.5 kW can be considered as optimal to guarantee navigability and limit energy costs [6]. By considering a ejectors plant lifetime of 10 years and yearly costs for operation and maintenance, a whole cost of 188,000 € over the 10 year has been computed (i.e. about 19,000 € per year) [6]. The cost is competitive with maintenance dredging, especially if indirect costs of dredging (i.e. permit/authorization, sediment analysis, limitation of towing basin operation due to navigability issues) are considered. The pilot plant is still in operation and under continuous monitoring.

The demonstrative ejectors plant in Cervia was more complex and its operation was accompanied by an extensive monitoring plan [2]. The main objective of the ejectors plant installed in Marina di Cervia is to guarantee navigability at the harbour inlet while in operation. The plant consists of ten ejectors located at the harbour entrance as shown in Fig. 3. There are two pumps, each one feeding five ejectors. Each pumping line has an auto-purging disk filter: the auto-purging cycle is activated once the pressure drop in the filter reaches a certain level. The total pumped water flowrate is controlled by an inverter, while the flowrate for each ejector feeding pipeline is balanced through electro valves. The total installed power is about 80 kW. A local meteorological station has been installed to relate plant operation with sea weather conditions (i.e. wind intensity and direction).



Figure 3. Location of ejectors plant in Cervia [7].

The Cervia ejectors plant operated continuously from June 2019 to September 2020. Despite the numerous problems encountered [7], which have been solved or for which a technical solution has been identified, the effectiveness of the ejectors plant is demonstrated by the ability of the plant to maintain a navigable channel with a minimum water depth of 2.5 m, measured with respect to the mean sea level leaving the harbour; a condition previously never reached at the beginning of the summer season without dredging operation. With regard to efficiency, the ejectors plant's consumption was higher than expected: starting from January 2020 until July 2020 (with a peak in June 2020), the uncontrolled growth of mussels in the pipes and filters considerably increased the pressure losses in the system, forcing the pumps to work with higher pressure, but with the same flow rate, compared to the operating conditions recorded in 2019. Various technical solutions alternative to chlorination are under evaluation to prevent the proliferation of organisms in the pipes, such as low-frequency electromagnetism. For this reason, based on the data collected in the first period of operation of the plant and the measured water flowrate for the whole monitoring period, it is possible to assess the average consumption of each ejector in normal conditions equal to 3 kW, i.e. an annual consumption for the ten ejectors of approximately 252,000 kWh/year. Annual costs for operation and maintenance are still under evaluation and will be published in a future paper.

Environmental assessment

One of the main results of Cervia ejectors plant monitoring is related to the comprehensive monitoring of environmental impacts of plant operation, which includes: i) integrity of seabed sediments and communities, ii) underwater noise, iii) greenhouse gases (GHGs) and pollutant emissions through life cycle assessment (LCA). Possible impacts of the ejectors plant on sediment characteristics, benthic and fish assemblages need to be assessed simultaneously at a variety of spatial scales, encompassing the full extent of the environmental variability of the area where the ejectors are positioned. Sampling sites are located in one putatively impacted location in front of the Marina di Cervia and in four control locations, placed 600 m and 1200 m north, and 600 m and 1200 m south of the impact location respectively (shown in Fig. 4). Two sampling areas (~800 m² each), 20–30 m apart, were defined within each location. In particular, the impact location includes two distinct areas, the ejectors (I1) and the outlets (I2). Changes in time of the measured variables at each putatively impacted areas were compared to the whole range of control areas.



Figure 4. Map of Cervia research area.

The use of the ejectors plant technology resulted [8] in a reduction of the percentage of muddy fraction (Fig. 5A) and of the organic matter content (Fig. 5B) present in the sediment in the areas affected by the plant, compared to the initial values (samples taken in May 2018) conditioned by previous dredging), thus approaching the mean values observable throughout the study in the control areas.

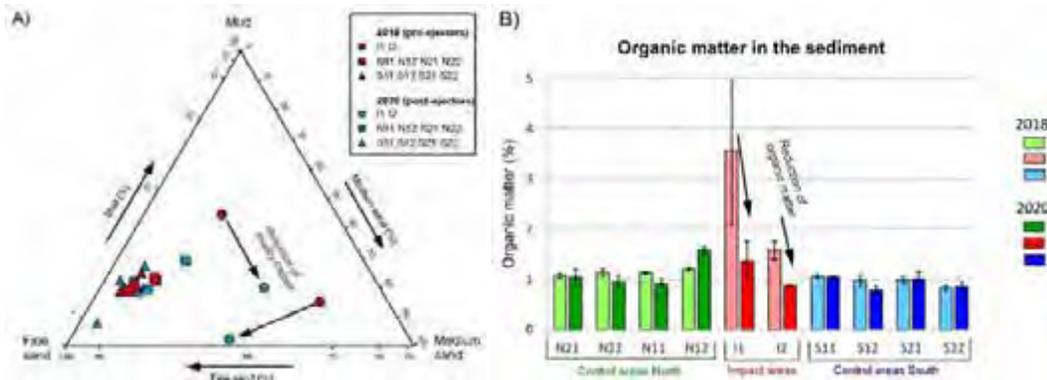


Figure 5. Proportions of the sediment granulometric fractions: medium sand >250 μm; fine sand 250–63 μm; and mud <63 μm (A) and percentage in weight of organic matter in the sediment (error bars based on standard error) (B) [8].

Species richness of marine macro-invertebrates (as shown in Fig. 6), initially reduced in the impacted area near the harbour, probably as a result of previous repeated dredging, significantly increased 8 months after the ejectors plant began operation (i.e. February 2020), although still remained below the average for control sites [8]. These results suggest an improvement in the ecological status of the marine ecosystem in the area affected by the plant within less than one year from the start of plant operation. A third sample campaign was performed in July 2020 and the preliminary results confirms the second campaign assessment: the results will be published soon in a dedicated paper.

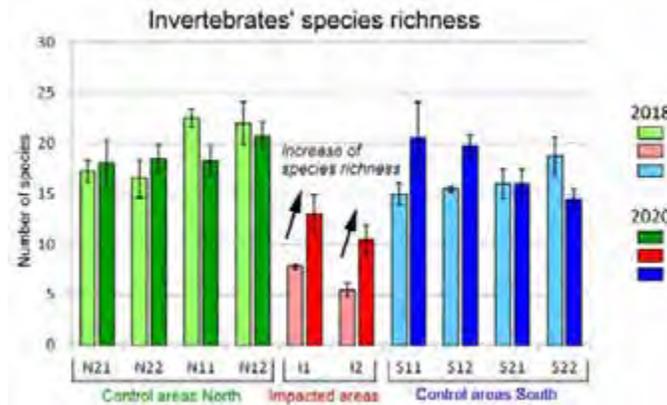


Figure 6. Mean number of macro-invertebrate species per sample in benthic communities (error bars based on standard error) [8].

The impact of the ejectors plant on underwater noise was assessed in September 2020 accordingly to [9]. The acoustic measurements were carried out by a specialised operator and by using the SQ26-05 sensor, a pre-amplified hydrophone produced by Sensor Technology. The measurements were carried out on five sampling points (see Fig. 7A): i) nearest point from the hydraulic pumps (B1), ii) 60 m from the hydraulic pumps (B2), iii) ~200 m from the hydraulic pumps and 150 m from point B2 (B5), iv) near the discharge point of the ejectors, approximately 50 meters away (M3), and v) ~185 m from point M3 (M4). Furthermore, the measurements were carried out with the ejectors plant shut off and with the plant in operation in three different conditions: manual control at two different speeds of the centrifugal pumps, plus automatic control (variable speed of the centrifugal pumps). While the assessment carried out in sampling points M3 and M4 relate to the impact on open marine environment, sampling points B1, B2 and B5 were measured to evaluate the impact of submersible centrifugal pumps for Marina di Cervia customers. All the acoustic data were analysed through MATLAB software. The ejectors themselves had no impact on underwater noise level if compared with the 'natural' baseline, while only in the case of monitoring point B1 a difference was found between the noise levels in the recordings made with and without the hydraulic pumps in operation (see Fig. 7B) [8].

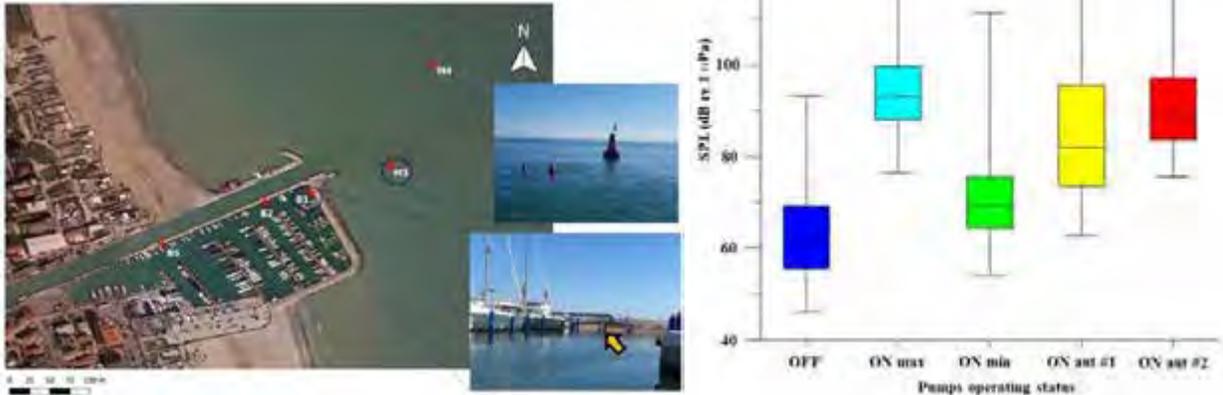


Figure 7. Locations of the five measurement points (A) and box-plot of the average SPL values (on the ordinates) for the different operating states of the hydraulic pumps (on the abscissas) (B) [8].

Nevertheless, the data were subjected to the Mann-Whitney statistical test for non-parametric distributions, to verify, in the presence of ordinal values from a continuous distribution, if two statistical samples come from the same population. The results obtained indicate that the difference between the measurements made with the inactive hydraulic pumps ('off' in Fig. 7B) compared with the measurements made with the hydraulic pumps 'on' and at different operating status (max, min and automatic control in day #1 and day #2) is not statistically significant ($p = 0.12$, which is greater than the significance value of 0.05) and therefore not attributable solely to the activity of hydraulic pumps. The conclusion is that from the analysis of the acoustic data, it emerged that in the harbour environment the impact of ejectors and hydraulic pumps to underwater noise level is insignificant.

Finally, the impact of the Cervia ejectors plant construction and operation on GHGs and pollutant emissions was assessed through life cycle assessment (LCA), accordingly to ReCiPe 2016 [10]. The categories selected to describe the impacts caused by the emissions and the consumption of natural resources at midpoints are Global Warming Potential (GWP), fine particulate matter formation (PMFP), photochemical oxidant formation (EOF and HOF) and terrestrial acidification (TAP). The impacts are strongly related with ejectors plant efficiency and is influenced by i) mean power consumption and ii) emissions related with power source. In the case of Marina di Cervia ejectors plant, the system was fed by the grid, therefore the mean specific emissions of the Italian grid were considered. Two different scenarios have been analysed in [8], one with lower efficiency (scenario #1, or 10 ejectors operating with 6.3 kW mean power consumption per ejector) and one with higher efficiency (scenario #2, or 5 ejectors operating with 3.5 kW mean power consumption per ejector): the results are shown in Fig. 8. Impacts can be strongly reduced becoming near-zero if the ejectors plant is fed by renewable power, which may be locally produced and/or purchased by the grid (i.e. certified green power). The comparison with dredging equipment is under evaluation and will be published in a future paper.

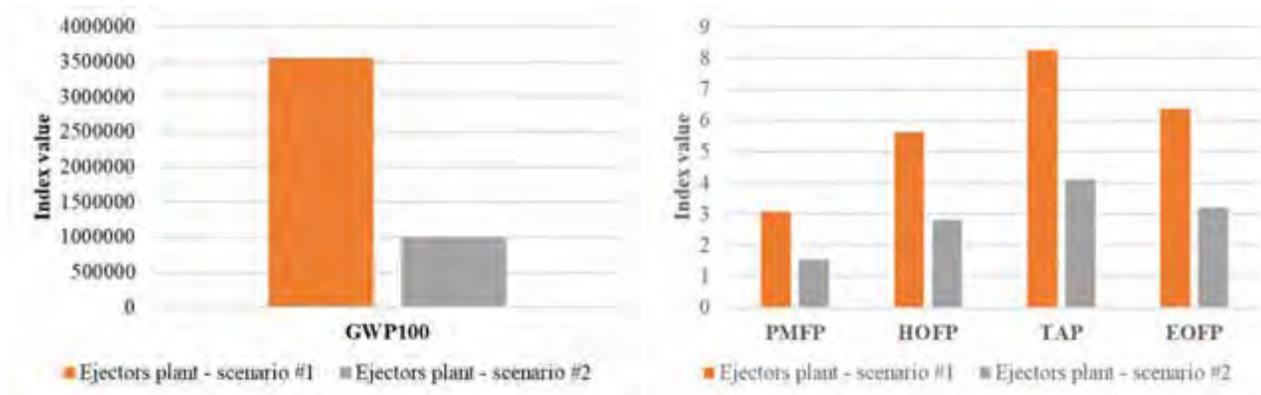


Figure 8. Comparison of midpoint characterisation between the two scenarios [8].

INTEGRATION OF EJECTORS PLANT TECHNOLOGY WITH NATURE-BASED SOLUTIONS FOR SEDIMENT MANAGEMENT

The International Union for Conservation of Nature (IUCN) defines nature-based solutions as “actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g., climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits” [11]. In riverine and coastal contexts, nature-based solutions include a variety of strategies and measures that rely on, or mimic, natural system processes to manage or reduce risk of flooding and erosion. Beach nourishment, stabilization, or restoration is perhaps the most familiar form of coastal nature-based solutions, with hydrodynamics and sediment transport phenomena playing a key role in related impacts. An example of nature-based solution application to beach nourishment is the “Sand Motor” project realized in 2011 by Rijkswaterstaat and the Provincial Authority of South Holland (Fig. 9A). The pilot project aimed to understand if natural processes (waves, currents, and wind) could work and redistribute the sand along the coast. By concentrating a single mega-nourishment at one location, the goal was to minimize long term ecosystem damage resulting from the sand placement, compared to smaller and more frequent nourishments distributed along the coast that impact a larger area and inhibit ecosystem recovery. The data [12] indicates that, in the first four years following its construction, the Sand Motor provided almost 1 million m³ of sand to the south coastline and 1.5 million m³ to the north coastline. Another example of coastal nature-based solution is the combination of dune restoration works and intertidal reef structures in Souris Beach, Prince Edward Island, Canada (Fig. 9B). The system was designed to dissipate wave energy, and encourage sediment deposition on the beach in front of the highway. Construction was completed in 2018 and post-construction surveying indicated that the solution performed with a small tombolo beach formation growing in the lee of the two reef structures. The resulting increase in the upper beach area has, in turn, led to growth and vegetation of the landward dunes. No repeat of the large shoreline recession measured in 2016 has been observed, despite significant storm events in November 2018 and September 2019 [13].

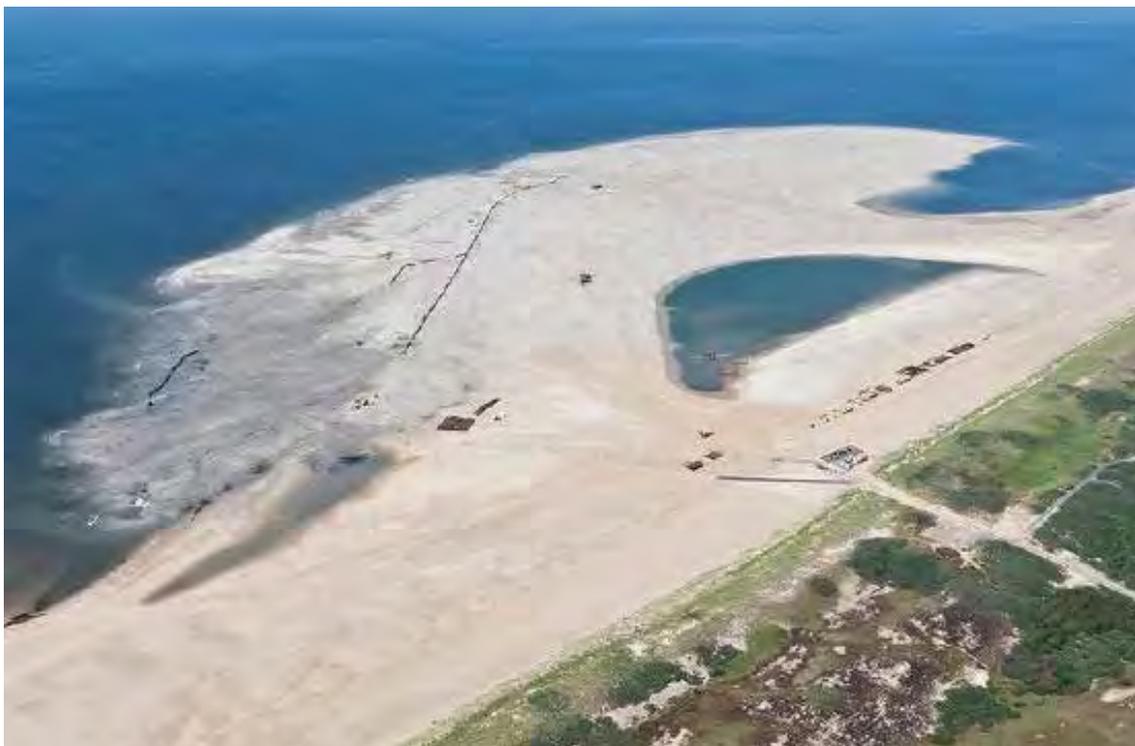


Figure 9. Examples [13] of nature-based solutions applied to coastal protection: the Sand Motor in The Netherlands (A) and Souris Beach Shoreline Erosion and Highway Protection (B).



Figure 9. Examples [13] of nature-based solutions applied to coastal protection: the Sand Motor in The Netherlands (A) and Souris Beach Shoreline Erosion and Highway Protection (B).

Preserving and allowing room or freedom space for natural river and floodplain system functions can reduce the degree to which people and infrastructure are exposed to flood hazards, and maintain or provide additional storage within the floodplain. An example of nature-based solution is the two-stage channel (Fig. 10), a modified versions of conventional trapezoidal channel: the main channel that conveys the river flow during normal conditions, and a floodplain bench that conveys water only when the capacity of the main channel is exceeded, mimic natural channel and floodplain function.

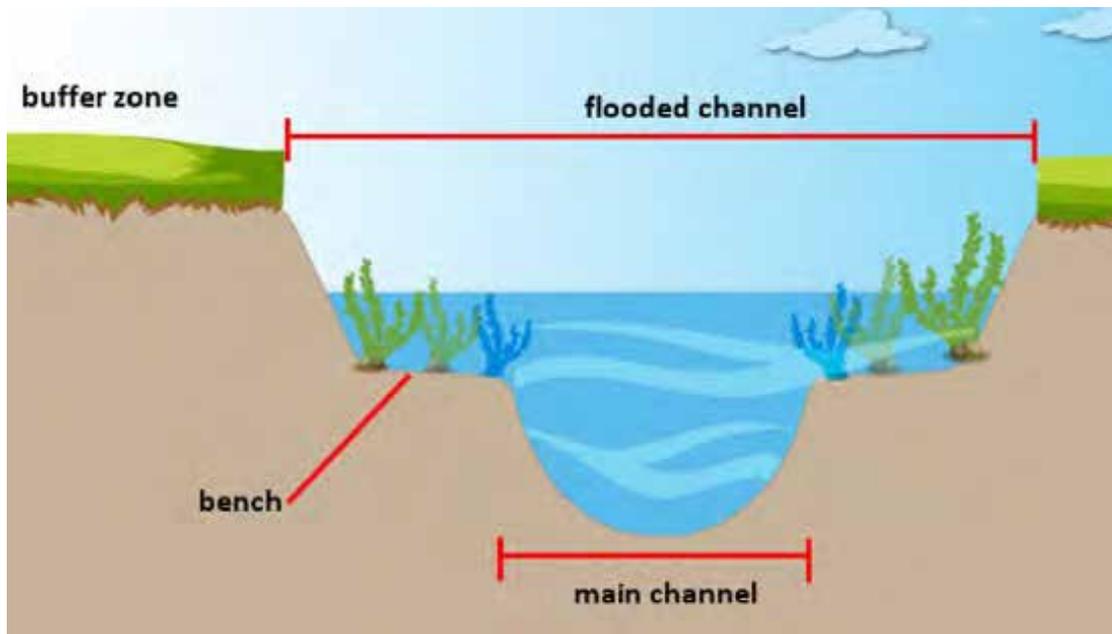


Figure 10. Two-stage channel concept [13].

The ejectors plant technology can be used in combination with coastal and riverine nature-based solutions since it is able to address localized and specific sediment management issues arising from natural sediment dynamics. Since the ejectors plant technology has near-zero local impact on the ecosystem, it can be integrated without compromising the expected benefits of nature-based solutions application on fauna and flora growth and habitat restoration. Nature-based solutions need maintenance actions, which include sediment management over the time. In anti-erosion and/or nourishment project the ejectors plant can play the role of ordinary and extraordinary maintenance of anti-erosion barriers, while in anti-flooding approach the ejectors plant can guarantee the desired water-depth of the main channel (also for navigation purposes) as well as the secondary channel and, at the same time, restoring benches from erosion.

EJECTORS PLANT FOR HEATING AND COOLING GENERATION AT DISTRICT SCALE

Large scale adoption of sustainable energy technologies is needed to reduce the use of fossil fuels. The global demand for heating and cooling in the built environment accounts for about 40% of the total primary energy. Therefore, the development and world wide application of renewable energy technologies in the field of buildings heating and cooling would contribute significantly to GHG emission reduction. Water source heat pumps (WSHPs) fed by renewable power can play a role in urban framework for building decarbonization. Different water sources like seawater, river, lake, groundwater or municipal sewage can be used as heat source or heat sink once coupled with heat pumps. The generation of heating and cooling can be at building scale or larger scale, i.e. district heating and cooling (DHC) networks, as in Fig. 11. In particular, innovative examples of applications of WSHPs can be found in the framework of low temperature or 4th generation DHC networks [14].

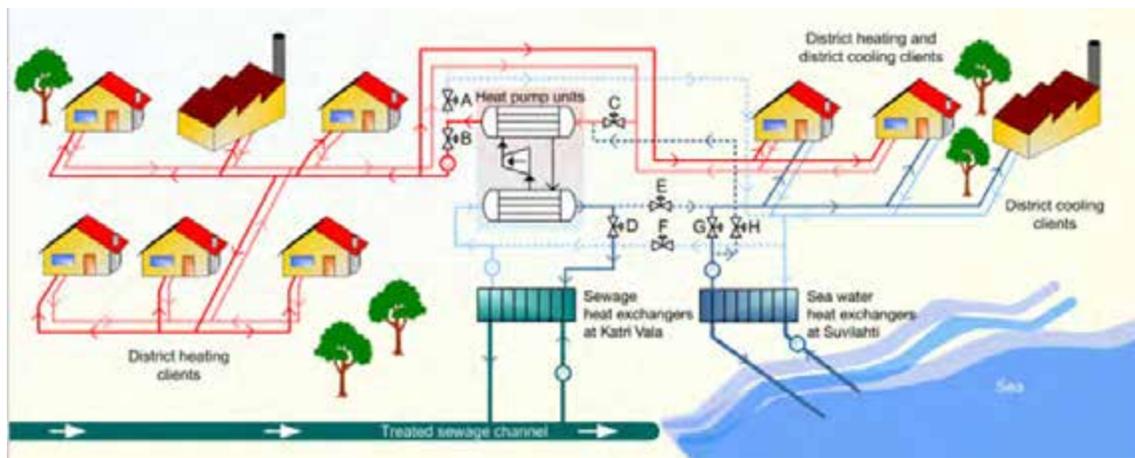


Figure 11. Example of water source heat pump integrated with district heating and cooling network (from FRIOTHERM website).

Water pumped to feed the ejectors can be simultaneously used for energy purposes via heat pumps. In fact, before reaching the ejectors, the pumped water can be used as heat source or heat sink through the integration in the traditional ejectors plant scheme of a properly designed heat exchanger (i.e. plate heat exchanger). Based on the more recent experiences of Cervia and Cattolica, it can be observed that a mean water flow rate of 30 m³/h is consumed per ejector, corresponding to approximately 8.3 kg/s. Depending on national and regional legislation, the water source can be used for heating and/or cooling purposes with some limitations in temperature variation. The authors assume that a 5°C ΔT increasing or decreasing can be acceptable in many Countries. Based on Eq.1, for each ejector the available thermal power Q is about 174 kW_{th}, being m the mass flow rate (in kg/s) and C_L water heat capacity (in kJ/kgK).

$$Q = m \cdot C_L \cdot \Delta T \tag{Eq. 1}$$

Therefore, if the same water used for ejectors feeding is used for free cooling applications in summertime, a cooling effect of about 174 kW fr per ejector could be expected. While in wintertime, the same water can be used as heat source for a heat pump. If a coefficient of performance (COP) equal to 3 is assumed, the heat pump may deliver about 261 kW th at 60°C by consuming additional 87 kW el per ejector. The potential dual use of water in ejectors plant as i) substitute of dredging operation and ii) heating and cooling plant can strongly reduce the operation and maintenance costs requested for both sediment management and buildings heating and cooling in areas closed to water sources. For example, a 10-ejector plants can guarantee navigability in a channel of about 100 meters length and, at the same time, being able to deliver energy to buildings, i.e. 1.7 MW fr in free cooling mode and 2.6 MW th in combination with a heat pump. The buildings may be not necessarily located close to the water source thanks to integration of thermal energy into DHC networks.

CONCLUSION

The ejectors plant, an innovative technology for sediment management in water infrastructure, has been tested and validated in the last two years through demo plant applications at the port entrance of the Marina of Cervia and in the Tavollo river in Cattolica (being both installations in Italy). The monitoring activities involved several actions, which include effectiveness, efficacy, and environmental impact assessment. The ejectors plant technology demonstrated to be effective in guaranteeing navigability over the time at reasonable costs and with near-zero impacts on the environment. In particular, in comparison with traditional dredging equipment, the ejectors plant technology can effectively manage sediment without impacts on marine flora and fauna, reduced underwater noise emissions and ideally no pollutants and GHGs emission, if powered by renewable energy sources. The explores the opportunity to integrate ejectors plant technology with nature-based solutions and buildings heating and cooling. The environmental friendly characteristics of the ejectors technology make it the perfect tool to perform maintenance activities on nature-based solutions designed to address both erosion and flooding risks, since it can solve localized issues deriving from sedimentation without altering the ecological status of the operation area. Moreover, the water used to feed the ejectors and transport the undesired sediment can be used also as heat source or heat sink. In particular, the integration in DHC networks is an interesting option to further increase the positive impacts of the ejectors plant and to reduce the operation and maintenance costs for both sediment and building energy management.

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REPLICABLE WATER SENSITIVE RESIDENTIAL MODULES: CASE OF NEW DELHI

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ABSTRACT

Cities in developing regions of the world, are facing an unprecedented combination of factors. These include - population explosion; resource stress; climate change; political, economic, and now health-related uncertainties. This presents a high-stake situation, where Sustainability although essential is no longer enough. Thus, this research proposes moving beyond sustainability – towards Resilient, Regenerative and Responsible Cities (S+R3). The Paper proposes the development of replicable water sensitive residential modules at multiple scales – City, Zone, Sector, Group in New Delhi. These can be adapted to urban conditions such as – retrofit, redevelopment, new development. The Methodology is an adaptation of mixed approaches from existing works. It has 3 sections – Mapping, Calculations, Analysis. The study looks at a transition from the existing water stress situation to a potential water sensitive scenario. The main outcomes of the study include – Sustainable (S): Overall water demand of residential plots can be reduced by upto 70%; Resilient (R1): Decentralised collection and treatment creates a crisis buffer for 30% potable and 100% non-potable needs; Regenerative (R2): After 100% non-potable needs are fulfilled, there is surplus treated gray water for recharging groundwater reserves; Responsible (R3): Local treatment can reduce central load from residential areas by upto 75%. After 100% non-potable needs, there is surplus treated black water for city needs.

KEYWORDS

Water sensitive, Delhi, Residential modules, Sustainable, Resilient, Regenerative, Responsible

INTRODUCTION

Cities in developing regions of the world are facing several pressing issues such as population explosion; resource stress; climate change; political, economic, and now health-related uncertainties. In particular, one major common issue is of Water Stress. According to a sub-national Water Stress Index, 11 of India's 20 largest cities face an 'extreme risk' of water stress; which includes Delhi, Chennai, Bengaluru, Hyderabad among others (Dua, 2019).

Water stress

'Water Stress' is when the demand for water exceeds the current available resource (quantity); or when poor quality restricts its use (European Environment Agency, n.d.).

Quality – Areas unconnected to the sewage infrastructure are forced to release untreated wastewater into the environment. Looking at residential areas, around 80% (WWAP (United Nations World Water Assessment Programme), 2017) of the domestic water supply is converted to wastewater. These large untreated volumes cause pollution of both surface and ground water bodies. This also has adverse health implications (R. Singh, 2010) for humans, flora and fauna coming in contact with these water sources.

Quantity - Demand for water in cities is increasing rapidly due to various factors. *First*, is an absolute increase due to growth in population numbers (Wankhade et al., 2014). *Second*, the country's economic development is also reflected in increasing per capita incomes, which encourages consumeristic lifestyles (Harvey, 2008). This leads to a direct increase in demand for water through water-intensive showers, vehicle washing, landscaping etc.; or an indirect increase through demand for products produced by water-intensive industries. *Third*, city water demand also increases due to inconsiderate wastage of the resource, despite households being capable of conservation and massive savings (Rohilla et al., 2017). *Fourth*, effective demand increases due to large percentage of leakages, pilferage and non-revenue water (National Institute of Urban Affairs, 2015). This increased demand, coupled with poor supply leads to overexploitation and depletion of water resources, particularly groundwater due to excessive unchecked extraction.

Replicable Water-Sensitive Residential Modules for Delhi

This paper tries to help address a part of the **Water stress** situation in Delhi. Delhi is being considered for the study due to the following factors - 1) its unmatched growth compared to other mega regions (United Nations, 2018), 2) its place as a major global city, possibly spearheading solutions for other cities of similar scale; 3) its position as the capital city of India, where it could lead the way as a model for upcoming urban areas, small and medium cities of the country.

This research proposes 'Replicable Water-Sensitive Residential Modules' through an S+R3 framework, towards addressing this Water Stress. While Sustainability is important, the reduction of harm in itself, as implied in the concept of Sustainability, is gradually becoming an inadequate response. There is need for positive regenerative action as also suggested in 'Trajectory for Ecological Design' (Reed, 2007). Taking this thinking forward, this paper advocates the need for R3 in addition to S, i.e. **S+R3** : Sustainability, Resilience, Regeneration, Responsibility.

The paper uses the term '**water-sensitive**' in relation to water-sensitive urban development or WSUD. In addition, it is used to emphasise the 'sensitivity' of a certain urban typology towards water. This sensitivity could enable the transition from a water-stress situation, to one that is water-sensitive. The term 'sensitivity' has been used in the context of existing literature, as a measure of vulnerability to climate change (Makame & Kangalawe, 2018) (Döll, 2009), and crisis such as water scarcity (Mekonnen Mesfin M. & Hoekstra Arjen Y., n.d.), as a benchmarking tool for practices (Rogers et al., 2020) sustainability, resilience and productivity in the face of climate change, rapid urbanisation, degraded ecosystems and ageing infrastructure. Indicators can be valuable for guiding actions for improvement, but there is not yet an established index that measures the full suite of attributes that constitute water sensitive performance. This paper therefore presents the Water Sensitive Cities (WSC, as a measure in behavioural science (Ozkazanc & Yuksel, 2015) morphological and climate characteristics. Earthquake, flooding and landslides are the premise fields along these disasters. Furthermore, devastating earthquakes, floods that are seen as a result of global climate change has led to significant loss of both life and property in the region. On the other hand, human-induced disasters, as well as natural disasters, have become increasingly risky and harmful to society in Turkey. Especially in recent years mining accidents in Kozlu, Soma and Ermenek resulted in the loss of large number of workers lives. All these cases reveals the urge to be prepared against disasters in Turkey. The first condition for being prepared against disasters, is by educating the society (individuals. This meaning is being taken forward towards the concepts of resilience, regeneration and responsibility. These concepts for the proposed modules are then supported through data and calculations.

Significance and Applicability of utilising Residential units

This paper is focussing on **residential units**, particularly **Group Housing** for the following reasons -

1. Delhi has a high demand for housing, particularly affordable options, since it is a growing city composed of migrant and floating populations. The situation of the cities of Delhi and Mumbai is unique, as they attract large percentages of migrants, specially from the states of Bihar and Uttar Pradesh due to educational and job opportunities in these cities; but also lack of jobs and seasonal nature of agriculture in the source states (N. P. Singh et al., 2011). More than 30% of the population in Delhi is composed of migrants, as according to the Socio-economic survey of Delhi, GNCTD, 2018-19 (Pandit, 2021);
2. According to the Master Plan for Delhi-2021 (Delhi Development Authority, 2017, p.33), group housing would constitute 42 percent of the housing component, which is a large percentage to target;
3. According to the Master Plan, this housing type would need to have a minimum of 35 percent of the total dwelling units as 2 rooms or less. This could cater to the economically weaker sections by creating more affordable options;
4. Group Housing is usually located on a plot, which according to (TCPO MoUD, 2016) is a parcel or piece of land enclosed by definite boundaries. This bounded condition would help speed up the implementation process, as defined boundaries would provide clarity about the area under intervention, for purposes of calculations etc.

The use of '**boundary**' in this paper in the above sense however, is only to leverage the properties of this typology in favour of improved water management for the city. Here, the term 'boundary' is also used in the sense of Elinor Ostrom's first principle for managing common pool resources - "Commons need to have clearly defined boundaries" (Williams, 2018), since water, particularly groundwater is a contested and fast-depleting common pool resource. Even common pool resources are better managed by delineating boundaries, not just physical boundaries, but social ones regarding - 'who is managing the resource?' or 'for whom is it being managed?'. In the case of group housing, the physical boundary is already clear. In addition to this, the 'who is managing' is also well-defined, as these housings are usually managed either by the developer or by resident welfare associations (RWAs). This paper looks at the 'for whom is it being managed' portion. The residents of these typologies may enjoy a somewhat disproportionate share of resources compared to other sections of the city in terms of land and water. The physical boundary, and management could thus be used towards incrementally converting the typology into water-sensitive modules, towards a more equitable or fair use of these resources for the city.

Further, the replicable modules could be applicable in multiple situations of Delhi – Redevelopment, Retrofit, New development.

- Several **redevelopment** projects are being undertaken for Delhi's government housing colonies, which are converting low rise quarters to high rise apartments. These projects are being criticised (Menon & Kohli, 2018) on points of sustainability of their footprints, possibilities of increased congestion, pollution, and water problems. Water-sensitive modules could assist in these cases, where the projects could collect rainwater and treat their own wastewater, thus reducing reliance on the central water grid, instead of adding to its load.
- Also, many group housing which were built decades ago, are undergoing **retrofits** for byelaw and structural upgradation. These could incorporate such modules and solutions where feasible. There has also been a transition in master plan narratives since the 1960s, where the 1962 plan talks of migration of approximately 70,000 low income group people, where locations for their settlements would be earmarked. Also, it mentions the relocation of squatters to different parts of the urban area. The current Draft master plan 2041 encourages the development of rental housing in view of their affordability and flexibility (Delhi Development Authority, 2021). This move came in response to the Covid-19 pandemic which saw mass reverse migrations, when people struggled due to loss of jobs and poor affordability of housing. Water-sensitive modules could be utilised for such situations, where existing vacant government houses are being converted into rental housing (PIB Delhi, 2021).
- The modules can also be applied for **new development** through the 42% group housing proposed to be built as per master plan for Delhi-2021 (Delhi Development Authority, 2017, p.33), of which 35% units would be for economically weaker sections of people.

Research question

The research aims to answer the question -

How can Replicable Water Sensitive Residential Modules help address Water Stress in Delhi, using the S+R3 framework?

METHODOLOGY

The methodology is a mixed approach combining mapping exercises and water calculations for the residential modules.

Mapping

The mapping exercises (**Figure 1**) are based on literature survey, in particular master plan documents, and site study, for identification of base cases for the proposed modules.



Figure 1. Mapping exercises, 4 scales - city, zone, sector, group

Here, the maps show various scales that could be addressed through the proposed residential modules. The section below details out calculations for a single Plot. The 4th scale of mapping shows a GROUP of residential plots, each of which could potentially replicate the system explained for a single plot. Any surpluses created could be applied to close-by green spaces in the Group. Similarly, zooming out to the 3rd level, several groups of residential plots, make up a SECTOR. These sectors could have relationships with larger green areas of the city, such as nurseries or parks. Further, the 2nd level shows how multiple sectors form a ZONE in the city. And eventually how in the 1st level, how the CITY is made up of many zones. The maps and the calculations depict a hypothetical Proposed scenario. However, the Existing calculations and assumptions are based on site learnings, data and research papers. In this sense, this proposed scenario is applicable and possible in the city, and could result in the outcomes presented.

Calculations and Analysis

The water calculations, based on assumptions from various research papers, detail out the smallest scale - the plot. The calculations prove how the proposed scenario moves towards the S+R3 framework, through a reduction in demand, local treatment, as well as creation of surplus resources.

The following **Figure 2**, delves into the water calculations to arrive at the outcomes for the paper. Here 2 scenarios have been compared – EXISTING (**Figure 2**, Columns 2 and 3), and PROPOSED (**Figure 2**, Columns 4 to 8).

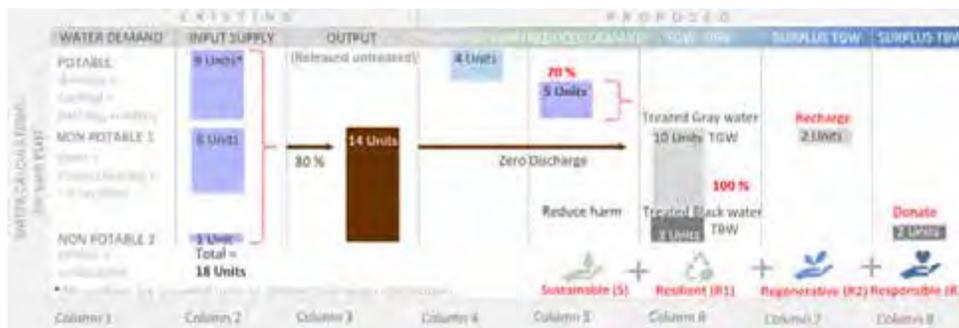


Figure 2. Water calculations for existing and proposed scenarios

In the **Existing** scenario, assuming the plot draws 18 Units INPUT SUPPLY (**Figure 2**, Column 2) from the municipality or the Central infrastructure for all its combined water needs. Cities usually use potable water from municipalities for both potable and non-potable needs, which is extremely wasteful as a practice.

So, to move towards the S+R3 framework, this input is first broken down, to understand the potable and non-potable components of demand.

- The **potable** uses in this case, drinking, cooking, bathing, washing need 9 Units (details of ‘Units’ are elaborated in the **Appendix**, after the References section) of Potable water (**Figure 2**, Column 1).
- Then, there are 2 types of **non-potable** demand –
 - Non-Potable type 1 is for toilet flushing, house cleaning, and car washing. In the existing situation this is using 8 Units of potable water. However, these uses do not need potable water and can utilise treated gray water.
 - Non-Potable type 2 is for garden/ balcony and landscaping. In the existing situation this is using approximately 1 Unit of potable water. These uses also do not need potable water and can even utilise treated black water.

In the Existing scenario, the OUTPUT wastewater which forms around 80% of the total input or 14 Units (**Figure 2**, Column 3), is released untreated into the environment, thus polluting surface and other water bodies.

Now in the **Proposed** scenario -

- Rainwater is harvested and treated to Potable quality within the site. This provides us with 4 units of Potable water (**Figure 2**, Column 4). Therefore, the potable demand reduces by 70% to just 5 Units (**Figure 2**, Column 5).
- Next, the wastewater from the site is also treated locally. This gives us 10 Units (**Figure 2**, Column 6) of treated gray water (TGW) and 3 Units of treated black water (TBW). This means that Non-potable demand type 1 is 100% fulfilled, with 2 Units as surplus (**Figure 2**, Column 7) TGW.
- Also, Non-potable demand type 2 is also 100% fulfilled, With 2 Units as surplus (**Figure 2**, Column 8) TBW.

Therefore overall input requirement remaining from the municipality is only the 5 Units of Potable water.

CONCLUSION

Thus, we arrive at the following outcomes –

- Sustainable (S) (**Figure 2**, Column 5): overall water demand of residential plots can be reduced by upto 70%;
- Resilient (R1) (**Figure 2**, Column 6): locally treated wastewater can take care of 100% non-potable needs;
- Regenerative (R2) (**Figure 2**, Column 7): surplus TGW can be used for recharging groundwater reserves;
- Responsible (R3) (**Figure 2**, Column 8): local treatment can eliminate release of untreated wastewater to the environment. Additionally, surplus TBW, can be donated for city needs like landscaping and street washing.

Therefore,

- Planned residential modules can be effective solutions towards addressing urban water stress.
- The resulting modules satisfy not only their own requirements, but also reduce pollution load from the city, while contributing resources to the city. Thus, they are not only Sustainable, but also create a positive impact – They are Resilient, Regenerative, Responsible.
- However, as mentioned earlier, the paper presents a hypothetical proposed scenario following the S + R3 framework. The calculations and assumptions are based on site learnings, data and research papers. In this sense, this proposed scenario is applicable and possible in the city, and could result in the outcomes presented. Future research could further look into details of applying this framework to different plot conditions in the city - Redevelopment, Retrofit, New development.

ACKNOWLEDGEMENTS

This paper was an unrealised idea, developing through many years of interest in the subject. It finally however saw light as an academic work, through an M.Phil. coursework subject assignment. For this the author would like to convey sincere thanks to Professor. Mukesh Patel, instructor for the course, ‘Research Practice, Analysis and Communication’ at CEPT University, Ahmedabad India.

Also, the author “received no financial support for the research, authorship, and/or publication of this article” (*Funding Acknowledgements*, 2015).

CONFLICT OF INTEREST STATEMENT

The author declares that there are “no conflicts of interest to disclose” (Herron, n.d.), concerning this study.

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APPENDIX

The following section of the paper has elaborated on the calculations for the representative rounded off values of ‘Units’ in million litres or ML, used for the existing and proposed scenarios in **Figure 2**.

Existing scenario

For the **Existing** scenario values from (**Figure 2**, Columns 2 and 3).

For **Potable** demand (**Figure 2**, Column 2)

According to (Biswas, 2009) as the supply cannot be increased due to scarce raw water resources. On the other hand the per capita demand of water is increasing in urban area due to higher standards of living and lifestyle changes. India’s urban population is increasing at a faster rate. According to the 2001 census, about 28 % of Indian populations (about 300 million pp. 126, potable water requirements in litres per capita per day (lpcd) have been used as per the **Table I** below, totalling to 135 lpcd.

Table I. Potable water requirements

| | lpcd | ML |
|----------|-------|-----|
| Drinking | 5.0 | 0.3 |
| Cooking | 10.0 | 0.7 |
| Bathing | 60.0 | 4.0 |
| Washing | 60.0 | 4.0 |
| Total | 135.0 | 9.0 |

Assuming 45 residential units and 4 persons per residential unit in a particular plot. The lpcd values are converted to million litres or ML using Eq. 1 below.

$$\text{ML value} = \frac{[\text{lpcd value} * 365 * (\text{No. of persons / residential unit}) * \text{No. of residential units}]}{1,000,000} \quad (\text{Eq.1})$$

Next, for **Non-Potable type 1** demand (**Figure 2**, Column 2) calculations,

According to (Biswas, 2009) as the supply cannot be increased due to scarce raw water resources. On the other hand the per capita demand of water is increasing in urban area due to higher standards of living and lifestyle changes. India's urban population is increasing at a faster rate. According to the 2001 census, about 28 % of Indian populations (about 300 million, non-potable requirements for toilet flushing and house cleaning equal to 90 lpcd. Additionally, assuming 40 litres per car per day (thebetterindia, 2020) (abbreviated as 'lpcd car' in **Table II** below). Assuming 2 cars per residential unit.

Table II. Non-Potable type 1 water demand

| | lpcd | lpcd car | ML |
|-----------------|------|----------|-----|
| Toilet flushing | 60.0 | | 4.0 |
| House cleaning | 30.0 | | 2.0 |
| Car washing | | 40.0 | 1.3 |

The lpcd values are converted to million litres or ML using Eq. 1.

The 'lpcd car' value is converted to million litres or ML using Eq. 2 below.

$$\text{ML value} = \frac{[\text{lpcd car value} * 365 * (\text{No. of cars / residential unit}) * \text{No. of residential units}]}{1,000,000} \quad (\text{Eq. 2})$$

Further, for **Non-Potable type 2** demand (**Figure 2**, Column 2) calculations,

Assuming balcony area of residential units = 6.7 sq.m. (18 sq.ft. * 4 ft balcony = 72 sq.ft.). This area is calculated from representative plan drawings for the units.

The area value of 386.2 sq.m. for landscaping as seen in **Table III** below, is measured through mapping exercises.

Table III. Non-Potable type 2 water demand

| | Area | ML |
|-----------------|-------|-----|
| Garden/ balcony | 6.7 | 0.8 |
| Landscaping | 386.2 | 1.0 |

The litres per week per sq.m. water requirement for plants has been taken as 50. This value depends on several factors and can vary. So, the higher side value is assumed (Humanity Development Library 2.0, n.d.). This is converted to litres per day per sq.m. = 7.1. Using the area, the million litre or ML value for balcony is calculated using Eq. 3 below.

$$\text{ML value} = \frac{(7.1 * \text{Balcony Area} * 365 * \text{No. of residential units})}{1,000,000} \quad (\text{Eq. 3})$$

Similarly, the million litre or ML value for landscaping is calculated using Eq. 4 below.

$$\text{ML value} = \frac{(7.1 * \text{Landscaping Area} * 365)}{1,000,000} \quad (\text{Eq. 4})$$

Proposed scenario

Further, looking at the calculations for the **Proposed** scenario (**Figure 2**, Columns 4 to 8).

For **treated rainwater** calculations as for (**Figure 2**, Column 4)

Delhi gets 0.611m of rainfall per year (Centre for Science and Environment, n.d.).

The amount of rainfall captured, depends on the surface of capture. Depending on the surface, there are losses such as evaporation, absorption into the ground.

Taking efficiency of Rooftop surfaces and Paved areas as 85%. Also, efficiency of unpaved areas (i.e. landscaping in the case of plot) is taken as 30% (Kinkade-Levario, 2007; Proksch, 2016). The areas of surfaces are measured through mapping exercises.

Rainfall captured in ML is calculated using the Eq. 5 below. The rainwater calculations are shown in **Table IV** below.

$$\text{ML value} = \frac{(\text{Efficiency \% of surface} * 0.611 * \text{Area of surface} * 1000)}{1,000,000} \quad (\text{Eq. 5})$$

Table IV. Rainwater calculations

| | Efficiency % | Area of surface | Rainfall captured in ML |
|----------------------------|--------------|-----------------|-------------------------|
| Rooftop | 85 | 1800 | 0.9 |
| Paved Areas | 85 | 5924 | 3.1 |
| Unpaved Areas/ landscaping | 30 | 386.2 | 0.1 |

Next, for **treated gray water** calculations for (**Figure 2**, Column 6),

Gray water production is taken as 60% of total water demand (Manna, 2018).

Assuming 4-6% reduction in volume of treated water in treatment process. Taking higher value at 6% reduction, we are left with roughly 10 units of treated gray water as shown in **Table V** below.

Table V. Gray water calculations

| | ML |
|--|------|
| Total water demand | 18.0 |
| 60 % of total water demand | 10.8 |
| After 6% reduction, treated gray water | 10.1 |

For **treated black water** calculations for (**Figure 2**, Column 6),

Toilet flushing has a requirement of 60 lpcd (Biswas, 2009) as the supply cannot be increased due to scarce raw water resources. On the other hand the per capita demand of water is increasing in urban area due to higher standards of living and lifestyle changes. India's urban population is increasing at a faster rate. According to the 2001 census, about 28 % of Indian populations (about 300 million as shown in **Table II**). Assuming 45 residential units and 4 persons per residential unit in a particular plot. We convert the lpcd value to million litres or ML using Eq. 1. Further, assuming 80% of this flushed water is available as waste black water. Assuming 6% reduction after treatment as above. The blackwater calculations are shown in **Table VI**, with roughly 3 units of treated black water.

Table VI. Black water calculations

| | ML |
|---|------|
| Water for flushing toilets | 3.90 |
| 80% of water for flushing toilets | 3.12 |
| After 6% reduction, treated black water | 2.93 |

THE URBAN HEAT ISLAND EFFECT IN DENSELY POPULATED URBAN AREAS AND ITS IMPLICATIONS ON ECO-CITY PLANNING: INVESTIGATION OF VERTICAL TEMPERATURE PROFILES IN DOWNTOWN VANCOUVER

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ABSTRACT

The urban heat island effect at the surface is influenced by the 3D characteristics of the local landscape, including vegetation cover and material types. However, little research exists exploring the effect of urban features on local vertical atmospheric profiles within dense urban areas. This study collected vertical temperature data with Remotely Piloted Aircraft Systems at four sites in downtown Vancouver representing varying levels of urbanization and surface coverage. Data was collected in the morning and afternoon in summer and winter. Temperature profiles were compared against percentage vegetation, tree canopy coverage, percentage impervious surfaces, building heights, and material types. A significant difference was noted between the four sites in summer (up to 4°C), but not in winter. In the summer, warmer air temperatures were found in the morning and afternoon at the most urban site with the highest building density, least vegetation, and most impervious surfaces, up to 120m, but surface temperatures at this site were cooler due to shading. Air above the park site was cooler throughout the day. Two sites located near the ocean did not behave as expected: one had high afternoon air temperatures despite proximity to heat mitigating features, while the other had lower afternoon air temperatures despite low percent vegetation and high imperviousness. Air temperatures at these sites were likely influenced by horizontal advection forces from land-sea breezes. Additional research on vertical temperature profiles in a wider variety of urban areas would be beneficial to better understand the impact of urban features on atmospheric heat.

KEYWORDS

1.0 INTRODUCTION AND BACKGROUND

As the world struggles with climate change and rising temperatures, the effect of urban landscapes on local temperatures is becoming a phenomenon of public concern. The Urban Heat Island (UHI) is defined as the existence of recognizably warmer temperatures within urban areas compared to those in rural areas [1, 2]. Urbanization has a significant effect on the surrounding atmosphere and is a driver of climate change through processes such as land degradation, deforestation, high proportions of heat-retaining materials, and increased per capita emissions of greenhouse gases [3]. Heat waves are often more intense within cities, and are correlated with adverse health impacts such as increased mortality among vulnerable populations such as the chronically ill, elderly, and young children [3, 4]. Heat also plays a key role in the chemistry of air pollution and photochemical smog formation [4,5,1]. At present, population distributions are shifting towards cities, and it is expected that 70% of the global population will live in cities by 2050 [3]. With so much of the population dwelling in urban regions, it is more important than ever for municipalities to adapt to rising temperatures with heat mitigating urban design strategies.

Vancouver has typically enjoyed a mild and temperate climate, and its urban design policy has historically focused on features that take advantage of periods of sunlight or on protection from rain [5]. Because of this historically temperate climate and resulting design policy, Vancouver may be more vulnerable to the negative impacts of increasing temperatures. The frequency of Vancouver's annual heat days – where the temperature exceeds 30°C – is expected to rise from two days up to 14 days annually by 2050[6]. Vancouver is thus a prime candidate for UHI research, with resulting knowledge allowing Vancouver to shift its urban design policy towards addressing rising temperatures.

With the aforementioned issues in mind, a detailed understanding of the urban atmosphere and its influence on the UHI is needed. Previous research on the UHI has been extensive, but investigations into the impact of the three-dimensional urban landscape on heat creation are more recent. Research specifically into the vertical structure of urban heat islands is limited, however. Remotely Piloted Aircraft Systems (RPAS, AKA drones) provide a simple, cost effective, and accessible way to measure the vertical characteristics of the urban atmosphere.

This research paper investigates whether urban characteristics and morphological features have an impact on the vertical temperature structure of the UHI within the dense urban landscape of downtown Vancouver. The objectives of this study are (1) to measure, analyze, and compare the vertical temperature profiles of four sites around downtown Vancouver with RPAS; (2) to assess whether the morphological features and characteristics of each site have any impact on the vertical temperature profiles; (3) to consider temperature profiles at each site in two separate seasons to assess seasonal variation; and (4) to consider the data and discuss results within the context of eco-city strategies, and apply the information gained to the City's and the Region's future heat mitigation strategies. Specifically, the City of Vancouver's Greenest City Action Plan [7], Vancouver's Urban Forest Strategy [8], and Metro Vancouver's Climate 2050 Framework [9].

2.0 LITERATURE REVIEW

2.1 The Urban Boundary Layer

The complex shape, structure, and thermal properties of metropolitan areas have a profound effect on the atmospheric conditions above cities [10]. In urban areas, the well understood atmospheric boundary layer (ABL) – the layer of the atmosphere nearest to the earth and which extends to approximately 0.8-1 km in height – is redefined as the urban boundary layer (UBL). The UBL is one of the least understood atmospheric regions, and thus is an area of considerable study in recent literature [10]. The UBL can be divided into two distinct layers: the roughness surface layer (RSL), which extends from the surface to about 2-5 times the average building height, dominated by spatially variable turbulent flow; and the inertial sublayer, a higher region of mostly homogeneous flow [10,11]. Within the RSL are two sub-layers: At the lowest level, the Urban Canopy Layer (UCL) occupies the space between the ground and the average height of the surrounding buildings. Above the average building height, a nameless, strong shear layer exists which is predominated by high winds and elevated turbulence and mixing [11].

Within the UCL, local turbulence has different characteristics from those seen in other layers. Local flow patterns are uniquely influenced by the changing surface roughness and the diverse thermal properties of urban materials within these regions [10]. Each unique local neighborhood microclimate within the UCL starts off in equilibrium with the surface beneath it. But as altitude increases, these small climate zones begin to mix, up through a transitional blending layer that eventually extends to the

top of the RSL. At the top of the RSL and beyond, relative consistency of flow is achieved in the ISL [10]. These characteristics all play into the urban surface energy balance, which drives the atmospheric processes above [10].

Despite the challenges encountered in characterizing it, the UCL is the space within which humans spend most of their time, and thus is a microclimate that cannot be ignored. The behaviour of air flow within the UCL is important because it influences the movement of pollutants. Urban pollution often worsens in high temperatures brought on by the UHI, due to photochemical smog production. Thus, the influence of the UBL and the UHI on pollution formation and dispersion mean they are strongly linked to human health and comfort [1,4,11,12,13,14]. An improved understanding of the vertical atmospheric profile of urban neighborhoods would contribute meaningful information to the impact that urban design parameters have on air pollution management and pollution related morbidity and mortality.

2.2 Urban Heat Islands: Overview and Causes

The UHI is an atmospheric phenomenon that manifests as a region of warmer temperatures within and over urban areas compared to the temperature of surrounding rural areas [1,2]. Health Canada [2] notes that this effect usually occurs over large metropolitan areas where built surfaces absorb large quantities of solar radiation during the day. However, the EPA [1] states that the effect has been noted even over smaller cities and towns, though the size of the temperature effect declines as the urban area decreases in size. The existence of built-up urban features has been observed to cause temperatures that are 2°C to 12°C higher than non-urban areas [1,4,2], with the highest temperature differences occurring at night [1].

The behaviour, features, and causes of the UHI have been discussed in a wide variety of literature sources [10,11], including provincial [4] and national guidelines [1,2]. According to Giguere [4], the main contributors to UHIs are low vegetative cover, high proportions of impermeable surfaces, urban morphology, greenhouse gas emissions, anthropogenic heat, and thermal properties of surface materials.

A major side-effect of urbanization is the loss of vegetation, especially tree cover. As vegetation is removed during urbanization, it is often replaced by impervious materials like asphalt, concrete, and buildings. This loss of vegetation decreases ground shading and reduces cooling of the air by evapotranspiration [1,5,11]. Furthermore, increased imperviousness causes an increase in runoff and reduced penetration of stormwater into the ground and soil. Normally, heat in the air is dissipated by the evaporation of moisture from the ground when temperatures increase. However, when impervious materials replace the natural ground surface this evaporative cooling process is disrupted [4,5].

To combat the UHI, some regions have implemented urban greening policies to boost the proportion of vegetation within urban areas. Policies often encourage green infrastructure such as green roofs and walls on buildings. Green roofs have been demonstrated to be consistently cooler than other roof types in summer, even light-colored roofs [1]. Other approaches include municipal tree planting strategies [8,9], and discouraging the removal of trees on private property [5]. The existence of urban parks instead of buildings can also decrease the surrounding air temperature by up to 6°C [4]. Rain gardens, infiltration trenches, natural retention ponds, and constructed wetlands are accompanying tools used in greening strategies for improving permeability and managing stormwater runoff and flooding.

The thermal properties of common urban materials including albedo, emissivity, and heat capacity also play a role in the formation of UHIs. Albedo is a ratio indicating the proportion of solar radiation received by an object that is reflected back from the surface rather than absorbed [4,11]. Darker colored materials usually have a low albedo, meaning they absorb more solar radiation than they reflect, causing the object to heat up and by releasing that energy warm the surrounding area. Lesnikowski [5] identified the abundance of dark roofs on single family homes in Vancouver as a common problem contributing to UHI formation in the city's many historic neighbourhoods.

Thermal emissivity, on the other hand, is a measure of a material's ability to release heat back to its environment [1,11]. Emissivity is dependent on a material's finish and on the temperature of the surroundings, which influence the rate of energy release. High emissivity materials hold onto heat longer and may increase the heating load of a building, or increase the heat of the nearby environment [15]. The heat capacity of a material, defined as the amount of heat required to raise a given mass of material by 1°C [16], also plays a role. Generally, materials found in cities have a higher heat capacity than natural materials such as soil or sand. This results in downtown metropolitan areas that can absorb and store twice as much heat as their rural surroundings, on average [1].

2.3 The Role of 3D Structure and Urban Morphology

The impact of 3D urban morphology on air temperature in cities has been studied by a number of researchers in recent years [eg. 17,18,19]. A consensus exists in the literature that the existence of vegetative features – specifically trees – is negatively correlated with temperature [5,17,18,19,20]. Gage & Cooper [17] used LiDAR (Light Detection and Ranging), a remote sensing method, to perform hexagonal cluster analysis of land cover patterns in Colorado and found that temperatures were higher in clusters where mean building height exceeded mean tree height, and cooler where trees were on average taller than surrounding buildings. Tian et al. [19] noted that the ratio of the volume of vegetation to building volume played a significant role in urban temperatures in Beijing, but only in predominantly low-rise neighborhoods. In high-rise neighbourhoods, vegetation volume was less important than the orientation of buildings to solar radiation. Both of these studies support the importance of tall, mature trees for the shading properties they provide, a view maintained widely in the literature [1,4,5,11].

Building orientation and shape has been flagged as a major contributor to microclimatic temperature variation in cities. The orientation of buildings in relation to solar radiation and prevailing wind directions was noted to play a role in temperature of the surrounding air by Lesnikowski [5], and Tian et al [19]. Urban morphology features within the UCL such as urban canyons and sky view factor (SVF) are also key players in neighborhood microclimates [4,11]. Generally, deep urban canyons found in denser, high-rise dominated landscapes have low SVF, meaning that less solar radiation can reach the ground surface. Low SVF correlates with lower temperatures during the day, due to the shading provided by tall buildings [18,19]. However, these same high-rise, low SVF neighborhoods also had comparably higher temperatures at night [18,19]. In urban canyons, solar radiation that does find its way between buildings is reflected back and forth, often being absorbed, released, and then reabsorbed by building materials within the canyon. Anthropogenic heat emanating from buildings may also add heat to the landscape [1,4,18]. All of these factors act to retain heat within urban canyon regions at night, resulting in observed higher night time temperatures. In contrast, neighborhoods with shorter buildings and greater SVF, despite getting hotter during the day, had more effective surface radiative cooling from urban materials and thus cooled off more quickly at night [18,19].

2.4 Exploration of Vertical Temperature Profiles

Despite the growing body of research on the influence of 3D morphology on air temperature in cities, most research to date has focused on the spatial distribution of heat at the surface level of urban landscapes [5,17,18,19,20]. As pointed out in some studies [10,21,22,23], research that has measured or looked at the vertical atmospheric features of the UHI is limited.

A variety of methods have been used to investigate vertical temperature profiles. Gorlach et al. [22], used satellite data to estimate the approximate height of the UHI effect over Moscow to be as much as 1500m in the summer. Lokoshchenko et al. [23] measured the upper boundary of the UHI over Moscow using a mixture of radiosonde data and sensors affixed to a TV tower and mast. The latter study concluded that the UHI extended approximately 400m above the city, in contrast to the results found by Gorlach et al. [22]. This difference could be attributed to the low spatial resolution of the satellite data compared to radiosondes and weather masts. Sugawara et al. [24] used tethered balloons to investigate the vertical structure of a local cool island above a city park.

The methods used in the above studies come with limitations. Satellite data is low in resolution and useful only for large scales, making it unhelpful for understanding the microscale structure of local UHI effects [22]. Radiosonde data is complicated by the thermal inertia of the sensors, meaning they experience a slight delay in registering the actual temperature and cannot keep up as the radiosonde gains elevation. This leads to a slight overestimation of temperature [23]. Radiosondes are also difficult to precisely control, presenting a challenge for obtaining consistent, repeatable data [12,23]. And while the use of meteorological masts or other tall structures for affixing sensors to is feasible, researchers must consider the influence of building heat on sensors, and may also face both cost barriers and practical height limitations with regards to how far up they can record data [12,13].

Another approach to estimating and understanding the vertical structure of the UHI is through statistical modelling. Wang et al. [25], estimated the height of the UHI over Beijing using experimental modelling. The temperature difference between the city and a rural control area extended up to about 0.8km in the summer, and 0.5km in the winter. This is a similar height to that found by Lokoshchenko et al. [23], despite the different climatic locations. Barlow [11] provides an extensive review of progress in modelling of the UBL, including temperature phenomenon like the UHI. While modelling of the urban atmosphere has come a long way, models still lack precision due to an incomplete understanding of the processes within the UBL.

2.5 Studying the Urban Atmosphere with Remotely Piloted Aircraft Systems

RPAS are a relatively new tool being used in atmospheric investigations, having only been applied to vertical temperature investigations in a small number of studies, many of which are feasibility studies. The use of RPAS for the collection of vertical temperature data could eliminate many of the limitations encountered with other methods favoured by atmospheric researchers [12,13]. Small RPAS can bypass the barriers faced by conventional piloted aircraft in studying the lower urban atmosphere. RPAS can also be precisely controlled and do not encounter the location inconsistencies faced by radiosondes. Mounted sensors can remain in position long enough to remove thermal inertia errors. RPAS are also able to hover away from structures to eliminate building temperature interference. The relative low cost and ease of access to small RPAS enables their broader use within the research community. In a feasibility study by Masic et al. [13] a small, in-house designed multirotor RPAS apparatus was used to investigate vertical temperature profiles over Sarajevo, in the pursuit of a cost effective, flexible methodology for measuring atmospheric inversions over an urban area. This feasibility study captured temperature changes over a vertical distance of 1km, and effectively identified temperature inversions. Adkins et al [12] presented a methodology for using “meteorologically instrumented” RPAS to investigate temperature, pressure, and wind speed within the UBL. However, the authors also noted a current limitation of RPAS: that the existence of tight regulations on flights within cities can restrict the breadth of available measurements, especially height. Other studies have successfully investigated other meteorological parameters in the ABL using RPAS, though not in relation to the UBL [21,26,27]. Nonetheless, these studies attest to the reliability of RPAS as a research tool for the atmospheric sciences.

3.0 METHODS

This project utilized an experimental research design. The methodology included direct atmospheric profile measurements, results analyses and the graphical and numerical presentation of atmospheric temperature profiles. Four locations were chosen within and around downtown Vancouver in order to capture a variety of different surfaces, materials, and urban morphologies. All locations fall within a fairly small geographic area of approximately 10km², which allows for an analysis of variability due to site features rather than horizontal distance between locations. Locations were chosen to represent the following four types of urban environment.

1. **Mediumly urbanized.** Mix of low and higher rise buildings and streets, with moderate vegetation, grass/park and tree cover, and a higher proportion of lighter colored pavement or gravel..
2. **Highly urbanized.** Many tall and medium sized buildings and streets, mixed residential/commercial, with lots of asphalt, concrete, and man-made surfaces, with little vegetation or tree cover.
3. **Urban with UHI mitigation features.** An urbanized location with buildings, streets, and man-made features, but also features such as green roofs or walls, parks/grass/gardens, and low albedo materials.
4. **Urban parkland.** A highly vegetated area with a large proportion of trees/grass/shrub or other natural features, and minimal man-made features.

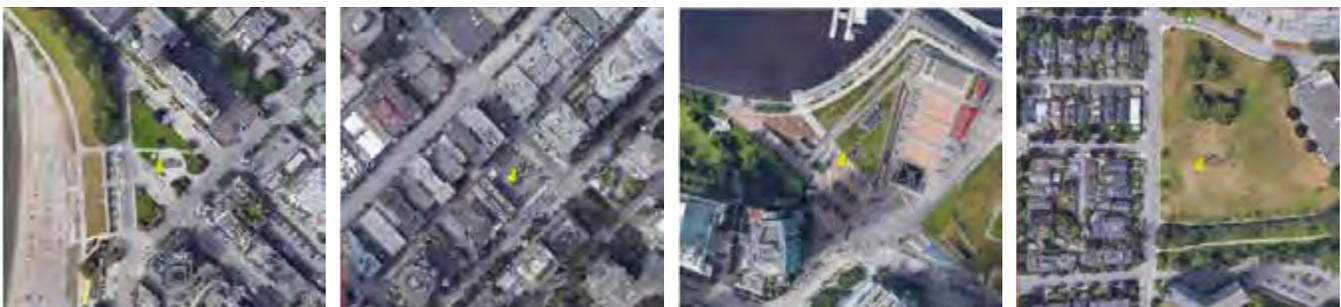


Figure 1: Google Earth Image of all sites – Site 1 Denman St. and Morton Ave; Site 2 - Seymour St. and Nelson St. in parking lot #83; Site 3 - Jack Poole Plaza near the Convention Centre West; Site 4 - SW Vanier Park at Chestnut St. and Creelman Ave

The sites chosen to represent each of the above four categories are shown on Google Earth satellite images included below in Figure 2. Exact locations of each site are noted in the corresponding figure caption.

As all of downtown Vancouver is within Class C controlled airspace, all flights must abide by Transport Canada regulations, and certified pilots must request individual approval for their flights from NAV CANADA and the Harbour Control Tower. Additionally, flights carried out in municipal and provincial parks or on private property require written permission from the property owners or managers.

At each testing site two RPAS were employed to capture temperature data at ground level and four different altitudes. Each RPAS rested at ground level (1m from ground surface) for a minimum of 10 minutes, launched and then hovered at two separate altitudes for 6-10 minutes per altitude. Data was collected at the following elevations above ground: 1m, 20m, 40m, 70m, and 120m. In Canada, 122m is the maximum allowable altitude for drone flights without a special flight operations certificate, which was not obtained for this study. In some cases, pilots received individual height restrictions of 90m, so in those cases the maximum height obtained was limited by NAV CANADA permissions. The range of altitudes chosen was intended to capture the top of the urban canopy layer in all locations.

Hovering the RPAS at two set altitudes rather than ascending the entire distance at a set velocity allowed sufficient time for the temperature sensors to adjust and overcome any thermal inertia. TMCx-HD Air/Water/Soil Temperature Probes were used, which have a response time in air of two minutes. The RPAS used in this study were the DJI Air, Mavic 2 and Phantom 4 Pro. All are small, multi-rotor (4) drones with a typical maximum flying time of 20 minutes. Battery life informed the 6-10 minute hover time, which allowed ample time for the sensor to adjust, plus a safety margin. Each sensor was connected to a HOBO U12-013 data logger, and housed in a small, lightweight metal dish. The housing apparatus was approximately 8cm deep, with the data logger and sensor resting on a 2cm thick layer of foam to provide insulation from any heat produced by the body of the RPAS. The sides of the metal housing also provided protection from direct solar insolation and air currents created by the rotor blades. Each sensor apparatus was secured to the underside of the RPAS and launched from a small 1m high platform.

Data was collected twice on each sampling day: at 10am and 3pm. These times were intended to capture temporal variation in air temperature over the course of the day. Testing was intended to be completed over a period of 8 months to capture seasonal variation in the atmospheric temperature profiles. Temperature variation between sites was expected to be more pronounced in the summer, however, the literature implies that the UHI effect still exists in the winter months, though to a lesser degree [1,22,23]. Data collection over multiple seasons thus allowed for observation of seasonal variability and an analysis of whether the UHI effect was present and persistent across seasons. Originally, data was intended to be collected in late summer, winter, and spring. Unfortunately, prior to the last round of data collection in the spring, a safety issue related to the ability of the drones to carry the sensor apparatus payload was encountered. This issue compromised the ability of the research team to safely complete the last round of flights. As a result, data was only collected in late summer and winter.

Table 1: Average Seasonal Temperatures for Vancouver Based on the First Two Months of Each Season [28]

| Season | Duration | Targeted Sampling Time | Ave Temp (°C) |
|-------------|------------------|----------------------------|---------------|
| Late Summer | Sep. 1 - Nov. 30 | September to early October | 15 - 20 |
| Winter | Dec. 1 - Feb. 28 | Mid January | 5 |

Data collection dates were targeted to capture temperatures representative of typical seasonal weather in Vancouver: late summer (warm, sunny weather), winter (cold, overcast weather). Late summer was selected rather than mid summer due to the constraints of the academic year, which runs from September to April. Late summer measurements were selected to target warmer days resembling summer temperatures as much as possible. Typical weather in Vancouver was defined as an approximation of average ground level atmospheric temperatures for the first and second month of the seasonal period, as outlined in Table 1.

Photographic documentation and written observations of each site at the time of testing was captured, describing the features of the site and the weather conditions. Weather data was retroactively collected from the nearest Environment Canada weather station (Vancouver Harbour CCS) for each launch time as a double check, including: temperature, relative humidity, wind speed and wind direction [29]. A $\pm 4^{\circ}\text{C}$ margin of error was considered acceptable.

To quantify the materials, surfaces, and urban morphology of each site, the site area was defined as a 0.25km x 0.25km square centered over the launch location. Satellite images from Google Earth, in combination with data from the City of Vancouver’s Urban Forest Strategy [8], were used to approximate the percent tree canopy coverage within each area, as well as the percent coverage by impervious surfaces. Google Earth satellite images were also used to approximate the amount and type of different kinds of surface materials within each site area. Types of surfaces considered include roof color (dark, light, or green roofs), asphalt, concrete, gravel, paving stones, grass/low vegetation, and trees. Corresponding albedo and emissivity values for each material type was also noted. Finally, the intensity of urban morphology was quantified based on average building height,

observed density of buildings, and the number of low (under 7 floors), medium (7-15 floors), and tall (over 15 floors) buildings present within the site area. Buildings that were more than 50% within the site bounds were included in the building count.

Collected data was compiled and displayed visually using graphs and tables for comparison and analysis. Air temperature at each altitude was determined by taking the average of temperatures logged by the sensor after the first 2.5 minutes sensor adjustment period at each altitude. For quality control, the first and last 30 seconds of hovering at each altitude was excluded from data consideration. Average air temperature was then plotted against altitude at each site and for each launch to obtain a graphical representation of the environmental lapse rates. The lapse rate at each site and for each date and launch time were also compared against the dry and wet adiabatic lapse rates (DALR and WALR, respectively) to determine atmospheric stability. Vertical temperature profiles were compared between sites and analyzed based on the characteristics of each site using a simple observational analysis. The goal was to characterize the vertical temperature profile of each location, understand if and how it varied between sites, and then explore possible correlations between the characteristics of each site and the temperatures profiles found there.

4.0 RESULTS

4.1 Site Characterization

Each of the four sites was characterized according to the methods described previously. A summary of site characteristics is included in Table 2. This section describes the results of each site’s characterization process.

Site 4, which was located in Vanier Park and chosen to represent the greenest and least urbanized area, had the highest percentage tree canopy (20%) and vegetation coverage (49%) of all the sites. Site 4 also had the lowest overall building height, with no tall buildings and only 1 medium height building to the south end. Site 4 was adjacent to a residential neighbourhood which account for approximately 40% of the site area. The remainder of the site consists of an urban park with grass and trees. The height of the UCL (i.e. the average building height), was calculated to be 10.1m, though this may be skewed slightly due to the single 14 story building. All other buildings were 1-3 stories tall. Site 4 is located about 0.5km from the Burrard Inlet to the north. Despite having the most vegetation coverage, Site 4 did not have the lowest proportion of impervious surfaces, or the lowest proportion of dark roofs and asphalt. Dark roofs and asphalt have the lowest albedos of those identified, and some of the highest emissivity values. In fact, Site 4 had the second highest proportion of dark roofs (25%), and the second lowest proportion of asphalt (21%) of all the sites.

Table II: Summary of Site Characteristics at all Four Testing Locations

| | Site 1 - English Bay | | Site 2 - Parking Lot | | Site 3 - Convention Centre | | Site 4 - Vanier Park | | | |
|-----------------------------------|----------------------|----------------|----------------------|----------------|----------------------------|----------------|----------------------|----------------|--|--|
| | Site data | Vancouver data | Site data | Vancouver data | Site data | Vancouver data | Site data | Vancouver data | | |
| General Features | | | | | | | | | | |
| % Tree Canopy Coverage | 9 | 10-20 | 12 | <5 | 11 | 5-15 | 20 | 15-20 | | |
| % Vegetation Coverage (all types) | 21 | - | 16 | | 29 | | 49 | | | |
| % Impervious Surface Coverage | 59 | 50-75 | 83 | >75 | 27 | 25-50 | 50 | 25-50 | | |
| Urban Morphology Features | | | | | | | | | | |
| Observed Density | Medium | | High | | Medium- low | | Low | | | |
| Average Building Height (m) | 24.5 | | 22.3 | | 81.7 | | 10.1 | | | |
| Tall Buildings (>15 floors) | 4 | 21% | 6 | 16% | 3 | 60% | 0 | 0% | | |
| Medium Buildings (7-15 floors) | 1 | 5% | 2 | 5% | 0 | 0% | 1 | 3% | | |

| | | | | | | | | | | |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|--------|------------|
| Low Building (<7 floors) | 14 | 74% | 30 | 79% | 2 | 40% | 33 | 97% | | |
| Total # Buildings | 19 | | 38 | | 5 | | 34 | | | |
| Surface Material Types: | % | | | | | | | | Albedo | Emissivity |
| Dark roof | 15% | | 37% | | 3% | | 25% | | 0.1 | 0.92 |
| Light roof | 8% | | 14% | | 4% | | 1% | | 0.4 | 0.9 |
| Green roof | 2% | | 3% | | 14% | | 0% | | 0.2 | 0.93 |
| Asphalt | 30% | | 27% | | 10% | | 21% | | 0.08 | 0.95 |
| Concrete | 6% | | 5% | | 10% | | 3% | | 0.225 | 0.8 |
| Gravel/Paving Stones | 2% | | 0% | | 23% | | 2% | | 0.15 | 0.9 |
| Grass/Low Vegetation | 10% | | 1% | | 4% | | 29% | | 0.25 | 0.93 |
| Trees | 9% | | 12% | | 11% | | 20% | | 0.165 | 0.97 |
| Other | 19% | | 1% | | 22% | | 1% | | N/A | N/A |

Site 2 was located in a parking lot at the intersection of Nelson St. and Seymour St., in the heart of the commercial district of downtown. This site was selected to represent the most urban and man-made landscape, with the highest predicted risk for UHI effects of the four sites. Site 2 had the most impervious surface coverage (83%) and the lowest vegetation coverage (16%). Most of the vegetation coverage was provided by trees, concentrated to the southeast corner of the site where all of the tall buildings – primarily high-density residential apartment complexes – were located. Site 2 had the highest number of total buildings (38), and the highest number of tall and medium height buildings. Despite this, the average building height of Site 2 was only 22.3m, due to the large quantity of low buildings (30) also present. The northwest two-thirds of Site 2 was comprised mostly of these low, commercial type buildings with flat, dark roofs and almost no trees or vegetated surfaces. Interestingly, the tree canopy coverage at Site 2 (12%) was not the lowest of the four sites, having a slightly greater proportion of tree canopy coverage than both Sites 1 (9%) and 3 (11%). It should be noted that because percent coverage of materials was estimated with a grid method using Google Earth images, there is a chance the difference is due to estimating error. For this reason, Sites 1, 2 and 3 could be considered to have approximately the same amount of tree canopy coverage. Despite the similar tree coverage, Site 2 still boasts the lowest total proportion of vegetation.

Sites 1 and 3 fall somewhere in the middle between the above two mentioned sites, with varying vegetation and material coverage. Site 1 was located in a small green area 120m to the east of English Bay Beach, near the intersection of Morton Ave and Denman St. Site 1 is the most exposed to prevailing ocean breezes, which originate from the west and northwest in the summer. This site is located in the West End, an affluent, well vegetated residential mixed zoning neighbourhood with many restaurants and retail stores. Site 1 had the lowest tree canopy coverage (9%), partially due to the large amount of beach included in the site area, and the site's proximity to several blocks of commercial zoning to the southwest with lower-than-average tree canopy coverage [8]. Site 1 has the second lowest overall vegetation coverage (21%) after Site 2, and the second highest impervious surface coverage (59%). The building distribution of Site 1 is mixed, having 19 total buildings within its area, 4 tall, 1 medium height, and 14 low height. The average building height at Site 1 was 24.5m.

Finally, Site 3 was chosen because of the two large green roofs within its bounds, in an effort to observe the mitigation potential of such features. Site 3 was the northern most site, located just west of the Vancouver Convention Centre West Building. This site was the closest to the ocean, at only 70m away, but is somewhat sheltered from prevailing winds that blow from the west and northwest and which would have to pass through the dense downtown area first. This site had the lowest overall number of buildings (5). Despite the small number of buildings, three of the buildings were either dense high-rise apartment complexes or commercial skyscrapers. Average building height for the entire site was 82m, however, all buildings were clustered in the southwest corner. If broken down, the average building height in the southwest corner is 129m, and for the rest of the site, 10m.

Site 3 has the second highest percent vegetation coverage of the four sites (29%). Most of the vegetation coverage at this site is from lower vegetation such as grass covering the green roofs, while tree canopy coverage at Site 3 is the second lowest overall (11%). Site 3 also boasts the lowest proportion of impervious surfaces (27%), however, 23% of the site is covered by paving stones, with a lower degree of permeability compared to gravel and surface vegetation.

4.2 Summer Vertical Profiles

Vertical temperature profiles varied significantly between all four sites in the summer time, both during the morning and afternoon launch times. Variation existed between the individual lapse rates at each site, as well as in the temperatures between sites. The maximum difference in air temperature (3.36°C) occurred in the afternoon at 40m, between Sites 1 and 2. Surface temperatures also varied between sites, with the largest difference (3.06°C) occurring between Sites 1 and 4. In the morning time, overall variation in air temperatures between sites was lower, and temperatures appeared to converge at the highest altitude of 120m. This is in contrast to the afternoon, where variation between sites was slightly greater overall, and temperatures did not converge at the 120m mark, though they did appear to start moving closer together. Vertical profiles from all sites are shown in Figure 3 and Figure 4.

Site 2 – the parking lot – displayed the warmest air temperature overall in both the morning and afternoon, though the surface temperature at Site 2 was only the second highest in the morning, and the third highest in the afternoon. Interestingly, the park location at Site 4 had the highest surface temperatures during both launches. At altitude, however, air temperatures at Site 4 were generally lower, and remained lower even through the increasing heat of the afternoon.

Both Site 2 and Site 4 displayed minimal change in atmospheric structure from the morning to the afternoon, but did increase in temperature, as shown by a shift of the vertical profile to the right. At Site 4, the sharp decrease in temperature seen from the surface to the lower altitudes is likely exaggerated due to requirement for the launch site to be on the sidewalk next to the park rather than in the park, due to launch restrictions in municipal parks, but may suggest an unstable atmosphere. Once in the air, the RPAS moved over the park and both the morning and afternoon profiles of Site 4 show a low-level inversion at 40m in the morning, sinking to 20m in the afternoon. This inversion decreased in thickness by the afternoon. Conversely, the parking lot location (Site 2) was the only site which retained a stable atmosphere throughout the day and did not exhibit any kind of obvious atmospheric inversion, instead having a possible, very minor ground-based inversion in the afternoon. A ground-based inversion occurs when cooling from the surface is trapped beneath a warmer layer of air above it. Figures 5 and 6 show examples of the vertical profiles of Site 2 and 4, respectively, in the afternoon, plotted against the DALR and the WALR to determine stability.

In contrast to Site 2 and 4, the Convention Centre site (Site 3), showed considerable change throughout the day. In the morning, Site 3 was the coolest site through almost its entire vertical height, and was nearly the coolest at the surface; being less than 0.1°C warmer than the coolest site (Site 1). The morning atmospheric profile at Site 3 was unstable low in the atmosphere, with a considerable inversion layer at 40m and above. Site 3 also had the lowest air temperature measured that day at 15.63°C . However, in the afternoon the atmospheric temperature profile of Site 3 changed considerably. At the surface level, Site 3 was the coolest at 20.0°C , but once in the air was the second warmest site overall. This site also displayed a ground level inversion to 20m, followed by a fairly steady temperature through 40m and 70m, with a slight uptick in temperature to 120m. This slight increase in the upper part of the measured atmosphere may indicate the beginning of a higher altitude inversion that was beyond the reach of the data collected for this study.

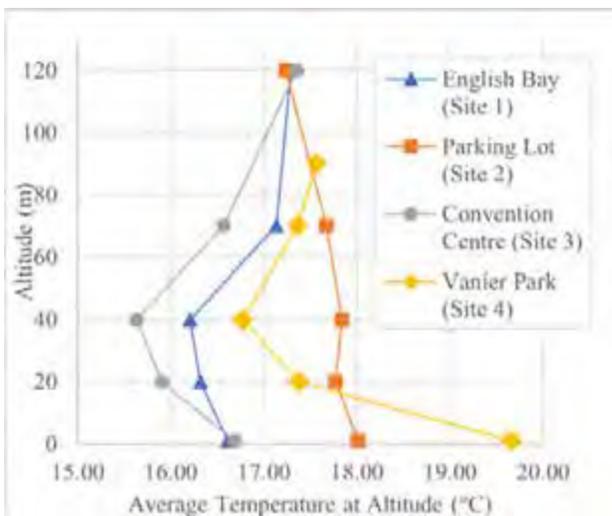


Figure 3: Combined vertical profiles of the atmosphere at all sites, morning launch (10am), summer

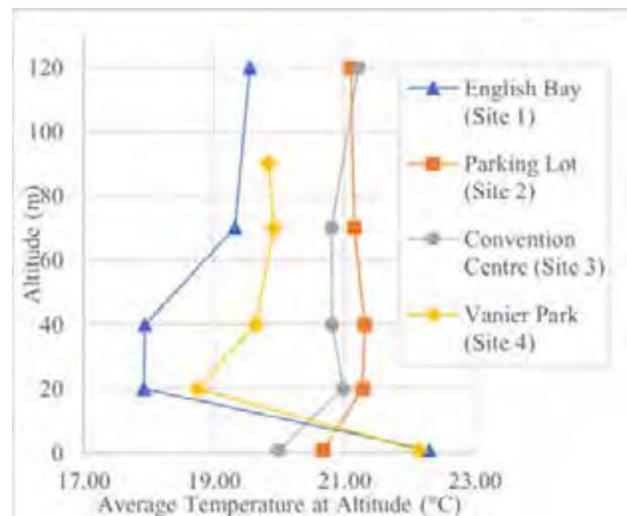


Figure 4: Combined vertical profiles of the atmosphere at all sites, afternoon launch (3pm), summer

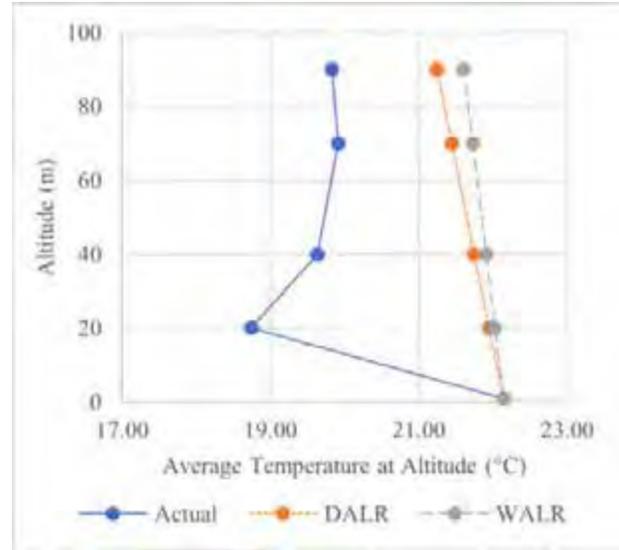
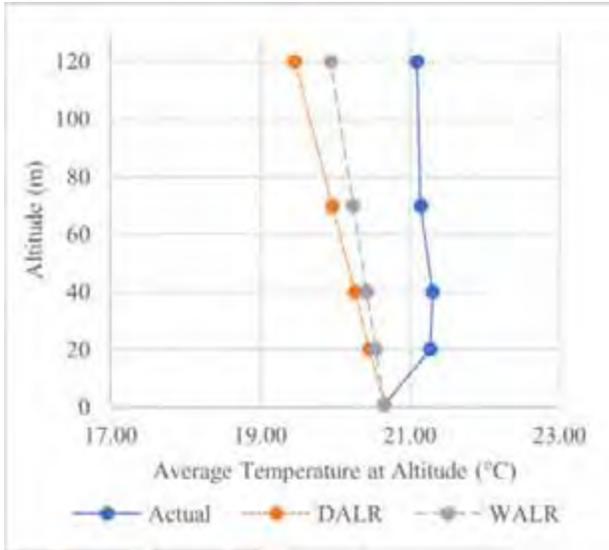


Figure 5: Vertical profiles of atmosphere at Site 2 during the afternoon launch, summer, with accompanying DALR and WALR

Figure 6: Vertical profiles of atmosphere at Site 4 during the afternoon launch, summer, with accompanying DALR and WALR

Site 1, at English Bay, was also peculiar compared to the other sites. In the morning, this site was one of the cooler sites, with a similar atmospheric structure to Site 3, albeit warmer by about 0.6°C. In the afternoon, the surface temperature of Site 1 became the warmest surface location overall, whereas the air above Site 1 was the coolest of the four sites. The temperature of Site 1 decreased from 22.30°C at ground level to 17.92°C at an altitude of 20m, a drop of over 4.38°C through a very unstable region. From the 20m point, air temperature was steady for a short time, and then entered an inversion from 40m and beyond. Surface and atmospheric temperatures with corresponding altitudes for the summer launches, which were completed on September 30, 2020, are provided in numerical form in Table 3.

Table III: Numeric Temperature Profile Data vs. Altitude at all Sites, Summer Launches, Sep. 30, 2020

| | Site 1 – English Bay | | Site 2 – Parking Lot | | Site 3 – Convention Centre | | Site 4 – Vanier Park | |
|----------------|----------------------|--------------|----------------------|--------------|----------------------------|--------------|----------------------|--------------|
| | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) |
| Morning, 10am | 16.6096 | 1 | 18.0162 | 1 | 16.6880 | 1 | 19.6657 | 1 |
| | 16.3179 | 20 | 17.7698 | 20 | 15.9016 | 20 | 17.3810 | 20 |
| | 16.2088 | 40 | 17.8379 | 40 | 15.6321 | 40 | 16.7762 | 40 |
| | 17.1371 | 70 | 17.6716 | 70 | 16.5689 | 70 | 17.3627 | 70 |
| | 17.2882 | 120 | 17.2377 | 120 | 17.3539 | 120 | 17.5657 | 90 |
| Afternoon, 3pm | 20.6641 | 1 | 20.6641 | 1 | 19.9952 | 1 | 22.1456 | 1 |
| | 21.2756 | 20 | 21.2756 | 20 | 20.9737 | 20 | 18.7433 | 20 |
| | 21.3021 | 40 | 21.3021 | 40 | 20.8077 | 40 | 19.6358 | 40 |
| | 21.1457 | 70 | 21.1457 | 70 | 20.7978 | 70 | 19.9151 | 70 |
| | 21.0957 | 120 | 21.0957 | 120 | 21.2090 | 120 | 19.8303 | 90 |

4.3 Winter Vertical Profiles

Overall, variation in the vertical temperature profiles between sites during the winter time was much less substantial compared to summer variations. Small temperature differences between the site profiles were present, but the atmospheric structure above all of the sites was similar. In the morning all profiles were warmest at the ground surface, ranging from 5.55°C at the Convention Centre (Site 3) to 6.31°C at English Bay (Site 1). As height increased, temperatures decreased most steeply in the first 20m of the atmosphere, indicating an unstable lower region. At 40m, all profiles experienced a slight decrease in their lapse rates, but still continued to decrease in temperature with elevation, through to the maximum recorded height of 120m. At 120m, Site 4 had the lowest air temperature (4.06°C), and Site 1 continued to have the highest air temperature (4.89°C). Throughout the entire vertical profile, temperature differences between sites remained fairly steady. A graphical representation of the vertical profiles at all sites are included in Figures 7 and 8.

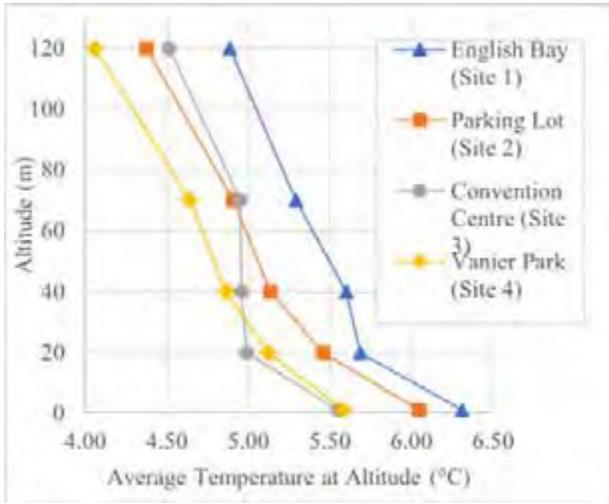


Figure 7: Combined vertical profiles of atmosphere at all sites during the morning launch (10am), winter

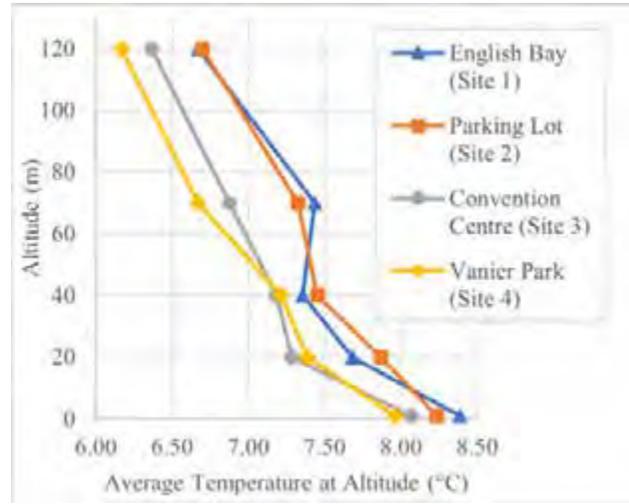


Figure 8: Combined vertical profiles of atmosphere at all sites during the afternoon launch (3pm), winter

In the afternoon, profiles were similar to the morning, with a bit more variation between sites in the 20-70m layer. Beyond 70m, all temperature profiles again continued to decrease until the 120m altitude. Surface temperatures in the afternoon were slightly closer together, ranging from 7.96°C at Vanier Park to 8.39°C at English Bay. At 120m, temperature varied from 6.17°C at Site 4 to 6.7°C at Site 2. During both the morning and afternoon launches, Site 4 had the lowest overall temperature. Site 1 at English Bay was the warmest of the four sites in the morning time. In the afternoon, Site 1 and 2 were warmest, having very similar temperature profiles. Site 1 also displayed the only potential inversion observed during the winter launch, though it was very slight. Due to the small difference in temperature (0.08°C) between 40m and 70m over Site 1, it is uncertain whether this was truly an inversion or merely a localized perturbation in temperature.

Stability of the atmosphere seemed fairly consistent across sites. In both the morning and afternoon, an unstable layer existed closest to the ground, up to about 20-40m. In the middle reaches of the measured atmosphere (20-70m), stability increased briefly, with all sites experiencing a layer of stability somewhere in this region. In the upper section of the measured column, all profiles again became unstable or conditionally unstable. Surface and atmospheric temperatures with corresponding altitudes for the winter launches, which were completed on January 29, 2021, are provided in numerical form in Table 4.

Table IV: Numeric Temperature Profile Data vs. Altitude at all Sites, Winter Launches, January 29, 2021

| | Site 1 – English Bay | | Site 2 – Parking Lot | | Site 3 – Convention Centre | | Site 4 – Vanier Park | |
|----------------|----------------------|--------------|----------------------|--------------|----------------------------|--------------|----------------------|--------------|
| Morning, 10am | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) |
| | 6.3105 | 1 | 6.0486 | 1 | 5.5512 | 1 | 5.5846 | 1 |
| | 5.6856 | 20 | 5.4596 | 20 | 4.9903 | 20 | 5.1222 | 20 |
| | 5.5993 | 40 | 5.1363 | 40 | 4.9581 | 40 | 4.8666 | 40 |
| | 5.2933 | 70 | 4.9068 | 70 | 4.9522 | 70 | 4.6418 | 70 |
| | 4.8868 | 120 | 4.3760 | 120 | 4.5147 | 120 | 4.0600 | 120 |
| Afternoon, 3pm | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) | Average Temp (°C) | Altitude (m) |
| | 8.3872 | 1 | 8.2352 | 1 | 8.0663 | 1 | 7.9644 | 1 |
| | 7.6824 | 20 | 7.8700 | 20 | 7.2830 | 20 | 7.3877 | 20 |
| | 7.3572 | 40 | 7.4531 | 40 | 7.1837 | 40 | 7.2142 | 40 |
| | 7.4352 | 70 | 7.3243 | 70 | 6.8779 | 70 | 6.6698 | 70 |
| | 6.6726 | 120 | 6.6968 | 120 | 6.3680 | 120 | 6.1673 | 120 |

5.0 DISCUSSION

5.1 Summer Vertical Profiles

An examination of the data from the summer testing day revealed some results that aligned with the hypothesis of the researchers, and some results that were unexpected. In this section, the observed influence of site features on vertical profiles will first be discussed for the morning flight, followed by the afternoon flight observations, and finally a review of general observations for the entire day.

Overall, Site 2, which had the highest proportion of impervious surfaces, the lowest proportion of total vegetation, and the greatest number of buildings, consistently had the warmest air temperature. This aligns well with the consensus in the literature that local warming is caused by the replacement of vegetation with low albedo impervious surfaces like asphalt and dark colored roofs [1,4,5]. In fact, in addition to having the highest overall number of buildings, Site 2 also had the greatest proportion of dark colored roofs, at 37%, and the second highest proportion of asphalt, at 27%. Both asphalt and dark roofing material have very low albedos, 0.08 and 0.1, respectively, meaning they absorb most of the solar radiation they receive. Once absorbed, these two materials also have fairly high emissivity rates (0.95 and 0.92, respectively), and are thus quite efficient at emitting heat back to the atmosphere to warm their surroundings.

Past research notes that the UHI effect is greatest at night, when man-made materials emit heat stored during the day back into the air in the absence of solar radiation, preventing affected areas from cooling overnight as much as they would normally [5,18]. The comparatively warmer morning surface and air temperature of Site 2 in this study support this theory, suggesting that the dense urban landscape and high number of tall buildings at the site insulated the local atmosphere from normal cooling. In comparison, the three other sites had a smaller total number of buildings, as well as a smaller number of tall and medium height buildings. Other research also noted the effects of tall buildings on local heat. Two studies identified that temperatures were higher where average building height was greater, noting that this effect was stronger than the effect of vegetation and tree cover in such neighborhoods [17,19]. Site 2 was also farthest from the Burrard Inlet, which may have played a role in reduced nighttime cooling ability compared to the more exposed sites.

Site 2 did not have the warmest surface temperature. In the morning, Site 4 (Vanier Park) was considerably warmer at the surface than Site 2, and in the afternoon, Site 2 had a lower surface temperature than both Site 4 and Site 1. Site 4's surface warmth is almost certainly due to the need to locate the launch area immediately next to the park on the concrete sidewalk because of RPAS launch restrictions within municipal parks. The sidewalk is surrounded by open grass and asphalt roads with no shading from trees. Once launched, the drone assembly was moved over the park for the remainder of altitudes.

Despite the warm surface temperature of the Site 4 launch location, once the drone was positioned over the park the air temperature at 20m declined by 2.29°C, making it ultimately lower than the air temperature of Site 2 by 0.39°C. This cooling trend continued to 40m, where Site 4 was 1.06°C cooler than Site 2 at 40m. This lower temperature suggests that the park has a cooling effect in the air above it, despite the fairly similar proportion of asphalt within the site area (27% at Site 2, 21% at Site 4). Despite being cooler than Site 2, the park was still warmer overall in the morning than Sites 1 and 3. This temperature difference may be attributable to the high number of low-rise buildings with dark roofs in the block adjacent to Site 4, or the cooling influence of the inlet on Sites 1 and 3.

Sites 1 and 3, which were the two coolest in the morning, had similar surface temperatures and exhibited similar vertical temperature profiles. Both sites were located quite close to the inlet and thus were likely influenced by the cooling effect of ocean, whereas Sites 2 and 4 are comparatively more protected. Gage & Cooper [17] noted a similar cooling effect in locations dominated by water. Ultimately, even with similar exposure to water, Site 3 at the Convention Centre had the coolest morning air temperature of all the sites. Proximity to the inlet and the higher proportion of vegetation at this site, including the large expanse of green roof on the nearby Convention Centre and restaurant are the most likely cause of this cooler temperature. These factors would have aided in radiative and evapotranspirative cooling during the night.

Vertical temperature profiles at each site changed considerably between the morning and afternoon test flights. As expected, temperatures at all sites warmed by several degrees. In the afternoon, the park at Site 4 appears to have retained its cooling effect in the air above the site. For the same reasons noted earlier, the surface temperature at Site 4 was quite high, but once above the park, the air remained cooler than both Sites 2 and 3. Site 4 remained cooler even at height, whereas Sites 2 and 3 experienced additional warming at higher altitudes compared to the morning. This suggests that the cooling effect of the park is persistent throughout the day, a notion supported by the literature [1,4,18]. The air was coolest immediately above the park at an altitude of 20m, after which it warmed slightly but still remained cooler overall.

Site 2 continued to have the warmest temperature in the afternoon, however its surface temperature dropped to third place, at 20.66°C. This cooler surface temperature is likely due to shading provided by surrounding buildings, a finding supported by other studies [18,19]. Visual observations from the site confirmed the presence of shading. Despite the cooler ground surface, the air above Site 2 was quite warm, indicating that the cooling effect experienced at ground level did not extend up into the UCL and RSL. In fact, the urban warming effect observed at Site 2 appears to have extended all the way up to the maximum measured altitude of 120m. With a calculated UCL height of 22m in this location, the warming effect thus extended beyond the tallest local buildings and as far up as the uppermost reaches of the RSL (calculated to be 110m). The high-altitude extent of warming could be attributed to a number of factors: trapped solar radiation within the urban canyon, anthropogenic heat released by the surrounding tall buildings through the height of the canyon and above, or the thermal properties of the building materials and facades.

Another result of interest from the afternoon test is the change experienced at the Convention Centre (Site 3). Whereas Site 3 had the coolest morning air temperatures, by the afternoon this Site's vertical temperature profile had shifted dramatically to the right, warming by 5.07°C at 20m, and 5.18°C at 40m. This is in contrast to the other sites, which warmed by 1.5-3.5°C at most. Given the higher proportion of vegetation at this site, the presence of the large green roof, and the cooling effects observed in the morning, this result was unexpected. The high degree of warming experienced at this site could be due to a horizontal advection of heat caused by the predominant wind direction. Being a coastal city, summer winds in Vancouver blow predominantly from the west and northwest [30], driven by sea breeze circulations. This meteorological phenomenon draws cooler air from the ocean towards the warmer regions over land, often becoming more pronounced in the afternoon and early evening [31]. A mild westerly wind direction is confirmed by observations recorded at the test sites, though wind data from the Vancouver Harbour CCS weather station was not available to confirm this [29]. Observations note that wind was calm in the morning, and increased slightly from the west in the afternoon. A westerly wind coming off the ocean would first blow across the warm interior of downtown and gain heat before blowing across Site 3 on the easternmost side of the downtown peninsula. This warmer air could displace cooled air related to the surface features of Site 3. A similar phenomenon was noted by Pigeon et al. [32], who observed heat fluxes in a European coastal city during a period of afternoon sea-breezes, noting that horizontal advection was the dominant process over vertical thermal advection processes at that time.

Two observations support the theory that horizontal advection is causing the increased temperature noted at Site 3. First, the section of downtown immediately east of Site 3 is dominated by high commercial skyscrapers averaging around 80m in height. This matches well with the extent of the warm air column, which reaches up to at least the 120m mark. When wind forces are acting on an urban surface, a plume of warmer air may be advected downwind of the city, which can expand beyond the height of the original layer from which it originates [11]. Second, Site 1, which is located on the opposite side of the downtown peninsula, had considerably cooler air temperatures than most of the other sites. Site 1 would be situated in the direct path of the

dominant sea breeze, which may explain why the air was so much cooler at this site, despite its higher proportion of impervious surfaces and low proportion of tree canopy coverage. In fact, the afternoon surface temperature of Site 1 was actually the highest of all four sites, which makes sense given its high degree of impermeability and relative lack of shading from trees. Site 1, however, then displayed the greatest drop in temperature between altitudes, dropping from 22.30°C at the surface to 17.92°C at 20m. This could be due to the inflow of ocean air just above the surface which acts to cool the atmosphere considerably. This evidence seems to support the flow of air across the city in a west to east direction.

Interestingly, despite the warmth of the air column, the surface temperature at Site 3 was the coolest of the four sites in the afternoon. It is unlikely that this surface cooling was due to shading from tall buildings, based on the small number of buildings present which are all far enough away to provide only minimal shading for the time of day. This may point to the fact that the high proportion of vegetation and the green roof at Site 3 were doing their job to keep the surface cool, but were overshadowed at higher altitudes by the horizontal movement of the plume overhead.

In addition to the local effects at each site discussed above, some general observations for the entire study area were also noted. First, air temperatures appeared to converge with increasing altitude in the morning, but not in the afternoon. These observations match well with descriptions of the urban atmosphere provided by Barlow [10]. In the morning, the surface of each site was cooler, therefore the unique warming effect of the local area would be expected to extend up only a short distance. However, as the surface was heated by solar radiation over the course of the day the vertical extent of warming above the site would be expected to increase. In either case, once a certain height is reached, local atmospheric forcings become negligible and air temperature should become homogenous due to mixing in the upper reaches of the UBL [10]. This homogeneity was observed at the convergence point in the morning profiles. In the afternoon, however, the reach of the increased warming effects from local features appears to have extended further into the atmosphere, as expected.

Finally, all sites except the parking lot exhibited what could be an atmospheric temperature inversion at around 40m. This inversion persisted into the afternoon at Sites 1 and 4, which were the western most sites, but disappeared at Site 3 in the afternoon, potentially overtaken by horizontal advection processes. Environment Canada did not have historical information available on inversions over Vancouver at the time of testing to confirm this observation. A frontal inversion caused by the collision of cool ocean air with warmer air over the city [33] is possible, and would align with the theory for why such a cool layer of air existed at 20m and 40m over Site 1 into the afternoon.

5.2 Winter Vertical Profiles

During the winter test day variation between vertical temperature profiles was much less pronounced. All four sites showed a fairly similar vertical profile in both the morning and afternoon, which was warmest at the surface level and decreased more or less steadily with height. Site 3 exhibited the greatest level of variation in the middle region with a period of steady temperature occurring from 20m to 70m, but otherwise had a similar profile in the lower and upper atmosphere. This could be a result of the eastern exposure of Site 3 to the warmer air above the inlet, which experiences an easterly prevailing wind direction in the winter. This is opposite to the prevailing wind direction experienced in the summer, due to a reversal of the temperature gradient over land and sea [31].

In the afternoon, all four sites again displayed a fairly similar atmospheric structure, with a zone of slightly increased variation in temperature between sites from 20m-70m. The upper bounds of the UCL, as determined by the average building height, was calculated to occur within this range at all sites. Therefore, it is possible that this slight variation could simply be due to the zone of increased mixing and turbulence that occurs in the upper half of the RSL.

It is possible that the thermal properties of the various surface materials and vegetation at each site were having a minor effect on the air temperature above, even in the winter. For example, Site 2 continued to be on the warmer side, and Site 4 remained on the cooler side. Since the heat capacity of materials is greatly reduced in the winter due to colder ambient temperatures and increased cloud cover interfering with solar radiative gain, it is expected that any UHI effects, if they existed, would be significantly reduced. However, site variations were very small and it is therefore also possible that observed variations were merely due to random fluctuations in the atmosphere. For this reason, it is not possible to say with certainty that local urban features had an impact on temperature variation between sites during the winter season. It is also uncertain whether the UHI effect was present in the study area at all during the winter. The inclusion of a distant data point outside of the larger Vancouver metropolitan area may have helped determine if a UHI was present, and should be included as a control point in future research.

Some sources of error may have existed during both testing days, but it is expected that they had minimal impact on the results. Firstly, some systematic error may have been introduced by imprecise instrumentation (i.e. the temperature sensors and drones). Due to the

format of this experiment and availability of instruments and RPAS, it was not possible to compare the instrumentation used in this study with other instruments to ensure accuracy or precision. However, any imprecision that might exist would be carried through to all of the results and should not influence the temperature variance observed between altitudes or sites. Some error may have also been introduced due to time delays between launches at some of the sites. For example, in the winter, flights at Site 3 had to be staggered due to a malfunction with one of the drone sensors that prevented the flight from being controlled in a safe manner. In this case, the first two altitudes were flown as planned, and then the drone was landed and the sensor apparatus and battery were switched before completing a second flight at the other two altitudes. For this reason, flight times were not simultaneous but occurred approximately 24 minutes apart. Small changes in temperatures may have occurred during the time taken to change out the sensor and battery, however, it is not believed that temperatures would have changed significantly enough during that time to impact results

5.3 Eco-Cities and Regional and Municipal Strategy Context

Ecocity Builders define cities as urban eco-systems, analogous in many ways to living, breathing organisms [34]. Cities are complex, dynamic, constantly changing entities that respond and adapt to their surroundings and the people, materials, and natural systems contained within them. The urban heat island phenomenon is the perfect example of how the complex interplay of energy and materials within a city can result in adverse consequences. Understanding and monitoring the material and energy inputs linked to UHIs is thus important to managing the health of our cities.

Ecocity Builders have created the International Ecocity Framework & Standards [35] to guide cities in taking a holistic approach to becoming sustainable urban organisms that can exist and thrive within the bounds of the planet. The framework includes 18 interconnected standards for municipalities to strive towards. Of these 18 standards, several have special relevance for UHI mitigation planning: (1) The standard for clean air, which deals with urban airflows and the movement of pollutants and GHGs; (2) the standard for green buildings, which encourages holistic, sustainable, and passive building strategies and considers the thermal impact of materials in cities; (3) the standard for healthy soils, which encourages a robust urban forest and ensures natural infiltration of rains and stormwater into the ground; and (4) the standard for access by proximity, which encourages pedestrian focused urban design that lends itself to increased vegetation, less impervious surfaces, and smaller, less sprawling cities. [35].

Features noted as significant in this study such as building materials, impervious surfaces, vegetation and trees, and building density, are major players in the above ecocity standards. When the relationships between these factors and urban heat are better understood, solutions can be identified. This study demonstrates that local-scale features likely play a role in the exacerbation or mitigation of urban heat in the atmosphere immediately above. When these microscale features are multiplied within a city, UHIs result. Therefore, understanding and correcting local features that are causing the exacerbation of heat on a broad scale is one potential pathway to reducing UHIs. And by extension, prioritizing ecocity standards in urban planning could achieve the same end.

A review of the City of Vancouver and Metro Vancouver's strategies and frameworks shows they are making significant steps towards identifying and addressing the issue of UHIs within the Ecocity framework. However, the strategies are lacking emphasis on the importance of building material selection, reduction of dark roofs, and green infrastructure such as green roofs and walls, which could further improve their strategies for managing urban heat.

6.0 CONCLUSION

The efforts of this study enabled the measurement and comparison of vertical air temperature profiles in downtown Vancouver for the first time. The study findings were able to corroborate the results of similar studies that analysed surface temperatures in urban landscapes, as well as identifying some new evidence. For example, results verified that high degrees of vegetation and tree canopy coverage such as urban parks have protective cooling effects, and that areas with greater degrees of impervious surfaces are warmer. Study results also supported theories about the impact of tall buildings on heat: specifically, that tall buildings insulate interior locations from normal cooling overnight, and that daytime surface temperatures in areas with greater urban canyons are cooler. However, this study also newly noted that the trapped air within urban canyons remains warm into the morning even at height, and that the daytime cooling effect noted at the surface of such locations does not extend into the air above. This warm column of air appeared to extend far up into the RSL, beyond the average building height.

Another finding of note is the possible significance of horizontal advection due to coastal sea breezes in heat distribution. One site studied, which was located next to several heat mitigating features such as a large green roof, a small urban park, and the ocean, was coolest in the morning but exhibited significant warming during the afternoon, against expectations. Dominant sea

breeze directions in the region may have blown warm air from the adjacent downtown core over the site, dominating the heat mitigating features of the site. This also speaks to the importance of having UHI mitigation features integrated across the entire downtown, as isolated mitigation features are not impactful enough on their own.

In summary, an improved understanding of the impact of local features on both surface temperatures and the air temperatures above will better inform UHI mitigation strategies. Mitigation strategies must be applied at the local scale, as well as the municipal and regional scale, in order to have a meaningful impact on improving city health and resiliency to climate change. Further research to observe vertical temperature profiles in a wider variety of urban locations, away from areas influenced by the ocean, would be beneficial to better understand the impact of urban features on local atmospheric heat. The City of Vancouver and the Metro Vancouver region are working on addressing the issue of UHIs within the Ecocity framework. However, additional emphasis on the importance of building material selection, reduction of dark roofs, and more green infrastructure could further improve the robustness of their strategies for managing urban heat.

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EVALUATION OF THE IMPACTS OF LOW-RISE BUILDING FORM IN URBAN TEXTURE ON THE MICROCLIMATIC WIND CONDITION

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ABSTRACT

Urban form as the geometrical shape of an urban area or neighborhood consists of several parameters and variables. The height and shape of the buildings, the street width, and orientation, the space between the buildings, and the urban topography and vegetation are the main elements of the urban geometry. Urban form can affect ventilation potential by causing flow turbulences around and at top of buildings which results in higher wind velocity. The positioning of adjacent buildings on streets and main streets of various widths on the right and left leads to the formation of “urban valleys” that direct the wind. In cases where buildings prevent airflow in hot climates, the comfort conditions of people moving in the city or outdoors are affected, and people/buildings in the interior have difficulty in making use of passive cooling facilities. Pedestrian comfort level is greatly affected by the temperature, relative humidity, and wind speed in urban canyons. Appropriate wind levels for the pedestrians increase the comfort in the cities situated in hot areas. Conversely, the high wind levels may also cause discomfort for the pedestrians in cases where the wind speed is over the comfort and danger levels. The duration and the intensity of the turbulence may also cause discomfort. The aim of this study is to investigate the effect of building orientation and forms, and street orientations in terms of pedestrian level microclimatic within the dense structure of the city of the case study area, which is considered in the historical texture of the Montenegro region.

KEYWORDS

Historical Texture in Urban Context, Urban Design, Air Exchange Rate, Pedestrian Level Wind Microclimatic Condition, The Effect of Building Orientation

INTRODUCTION

Due to the rapid increase in urbanization in recent years, urban microclimate studies are gaining popularity. In the meetings held by the United Nations in recent years, “making cities and human settlements climate-resistant and sustainable” has started to be promoted as one of the sustainable development goals [1]. Especially after the Covid-19 pandemic, which emerged all over the world in 2020 and caused the death of thousands of people by affecting their health, researches on sustainable healthy cities-habitats with the issue of natural ventilation of the city and buildings gain importance and will continue to gain importance in the coming years.

Approaches that emphasize microclimatic comfort sensitivity as part of the urban planning processes implemented to date are rarely included in the design process because there is a general lack of knowledge on how to do this among urban planning practitioners. Many studies conducted so far have documented that urban microclimate can affect building energy performance and occupant thermal comfort balance, especially its effects on human health. [2,3,4,5,6]. Urban comfort, which is the most important topic in the field of urban physics, deals with the relationship between wind/thermal comfort of pedestrians and pollutants and wind, which examines the urban air quality to ensure a healthy and happy life for the residences living in the city. Should the importance of urban form in urban design is developed in accordance with the context of urban microclimatic comfort, it can improve the quality of life of millions of people living in cities. The importance of climatically sensitive urban design is very important on the concept of sustainability, which has been a popular decision of recent years. Appropriate urban design enables the use of renewable energy sources for passive natural ventilation at city scale and passive heating and cooling at building scale while increasing pedestrian comfort and efficiency.

The Characteristics of Wind In A Built Environment

The average wind speed profile near the ground (interface layer) is governed by pressure differences due to the presence of buildings, vegetation, and topography. The nature of the obstacles regulates the turbulence level. When the wind velocity is greater than 10m/s, the influence of surface friction is predominant in distorting and generating a turbulent flow. Flow disruption depends on the shape and height of the obstacles. The wind does not reach a full-speed up to a certain height above the ground (called gradient wind); this height depends on local obstacles and is called surface roughness. Surface roughness and obstacles usually reduce wind speed, but can also have an acceleration effect on the wind. Occurs when airflow passes through a smaller cross-section (for example, passing through a building). It can also happen near tall buildings. Many features of the built environment and atmosphere affect wind speed. Wind speed in the built environment, therefore, exhibits a very complex behavior that is difficult to model.

Urban Physics and Microclimatic Comfort Analysis With CFD

When both the applications and the literature are examined, it is seen that the number of research studies and applications that take into account the wind, which is the most important parameter of the microclimatic comfort parameter in urban design, is inadequate. While most of the literature studies generally focus on the details and technical aspects of wind simulation used in the analysis, there are not many studies for urban planning practitioners on how they can apply wind simulation to improve their designs. This naturally means that wind simulation is not used enough in city planning at the moment, which reduces the quality of the outdoor urban area, and unqualified designs are produced.

The application of wind simulation in urban planning in conceptual design, schematic design, and detail design processes in the urban planning process can be preferred especially in schematic and detail design processes since the conceptual design phase is not very detailed by nature. During the schematic design phase, wind behavior between buildings can be considered on a rather macro scale. In the detail stage, wind analyzes may not be very effective in the wind-design relationship, since it is a scale that can be handled at the scale of the building envelope, and at this stage the settlement, shape-form decisions are determined.

There are four methods for analyzing wind speeds and directions. The first is on-site measurements. These provide detailed information, but extensive field measurements are time-consuming and expensive. They only work when analyzing current situations, so their use in predicting the impact of changes on the built environment is limited.

The second is the testing of scale models in wind tunnels. The modeling process itself is fairly simple and sensors can be used to get precise data on wind speeds, but it has two drawbacks. First, measurements are only made where the sensors are located, so their placement becomes critical to the results. Second, a wind tunnel is a specialized piece of equipment and not everyone has physical and financial access to it, which may be seen by urban planners as a barrier to its adoption.

The third method consists of simplified calculation methods. Rather than simulating the actual physical processes that together determine wind behavior, they use simplified, empirical mathematical models to predict wind speed based on surrounding urban geometry. These techniques have a relatively low computational cost but are also less accurate. There is also a lack of user-friendly software for the implementation of these techniques, making them less suitable for practitioners [7].

The fourth method of analyzing wind is Computational Fluid Dynamics (CFD). This is using a computer-based model to simulate real physical processes that together determine the behavior of the wind. CFD provides a complete picture of wind behavior across the entire model and is well established in a variety of fields, making it more accessible than field measurements, wind tunnel experiments, or simplified mathematical models in general. CFD is also becoming more applicable due to advances in computer technology [8].

Considering all the advantages and disadvantages, wind analyzes, whether alone or comprehensively as a part of microclimate analysis, cannot be used sufficiently in urban planning processes at present [6]. The barriers for CFD are lower than for other techniques, so CFD is the focus of this article. When we look at the historical background of urban microclimate studies, they have mostly been done with observational methods such as field measurements. In recent years, with advances in computational resources, numerical simulation approaches have become increasingly popular. Nowadays, especially Computational Fluid Dynamics (CFD) is frequently used to evaluate the urban microclimate. Computational simulations in urban physics and urban design studies can be used to study urban microclimate at different scales, from meteorological macro-micro scale to building scale [9,10,11]. Most of the CFD urban physics for microclimate studies have focused on parameters related to temperature, wind flow, thermal comfort, and heat transfer. CFD has repeatedly demonstrated its predictive ability in validation studies focusing on different parameters. CFD provides the possibilities of detailed indoor and outdoor comfort modeling of each building by evaluating inter-building microclimatic parameters at an urban scale. In the past, articles have been published that provide extensive reviews of meteorological micro-scale CFD studies [12,13].

Advances in the application of computational simulations in recent years have allowed them to develop best practice guidelines in urban microscale studies, so the popularity of the use of CFDs has continued to grow steadily [10,14,15]. Micro-scale CFD studies in urban design, pedestrian level comfort between buildings, wind flow around buildings [16,17,18,19,20] pedestrian wind comfort [21,22] pedestrian thermal comfort [23] the effect of wind-induced rain on buildings [24,25] it includes the distribution of urban air quality [26,27,28,29] etc. The smallest-scale studies using CFD on microclimatic analyzes at urban scale are the ones dealing with the indoor microclimatic comfort conditions of the building, where the horizontal distances between buildings are approximately 10 m and the focus is on the indoor climate. CFD has been used primarily for indoor ventilation studies and HVAC design issues in studies on this scale [30,31,32,33,34].

When the related article studies in the literature are examined, in addition to experimental wind tunnel tests and field measurements studies, numerical analysis studies with CFD have been increasing in recent years to examine pedestrian level comfort wind conditions in urban areas. Compared to both wind tunnel tests and field measurements, CFD has some advantages. One of the major advantages of CFD over wind tunnel testing is that it gives detailed flow area data of associated parameters across the entire calculation area.

Another advantage of CFD over wind tunnel measurements is that, in general, wind tunnel measurements are performed at only a few selected points in the model, while CFD provides a more detailed analysis of wind flow around the building(s) by providing data on relevant parameters at all points of the calculation areas [35,36].

The aim of this study is to investigate the effect of building orientation and forms, and street orientations in terms of pedestrian level microclimatic comfort and natural ventilation of pedestrian level comfort conditions in the urban area within the dense structure of the city of the case study area, which is located in the historical texture of Montenegro region. The aim is to answer the questions on the relation of the prevailing wind and the wind behavior in the built-up area. For this purpose, in the case study area of Montenegro, which is a historical settlement area, wind analyzes were carried out in 10 different directions (North, South, East, West, North-East, North-West, South-East, South-West, North- North-East, East- North-East) using the highest wind speed of 30.5 m/sec, considering the worst scenarios in the light of meteorological data, as well as cardinal and intercardinal directions as boundary conditions. In this study, only the analysis data of the four main direction will be evaluated.

This study focuses on the role of wind, which is the most important parameter affecting urban microclimatic comfort, which should be considered in the urban design process. Wind affects primarily urban air pollution and air pressure, as well as the energy exchange of buildings and users with the effect of convective heat transfer. Thus, it becomes one of the main driving forces of urban physics and urban microclimate. To evaluate the natural ventilation potential in the hot-humid climate of the

Bay of Kotor region of Montenegro, the air exchange coefficients of the buildings in the case study region were examined. In the study of Moreau and Gandemer (2002) on the evaluation of natural ventilation and pedestrian level comfort conditions in the urban area, a table is given about the air exchange rates of the buildings in the urban texture and the relationship between natural ventilation (Table 1). Guidelines are based on the pressure coefficient differential ΔC_p between upwind and downwind sidewalls of a building [37].

Table 1: Guidelines for Natural ventilation potential [37].

| Level of Natural Ventilation Efficiency | ΔC_p Range |
|---|-------------------------------|
| ACH too low | $\Delta C_p < 0.17$ |
| ACH enough | $0.17 \leq \Delta C_p < 0.39$ |
| ACH good | $0.39 \leq \Delta C_p < 0.53$ |
| ACH very good | $0.53 \leq \Delta C_p$ |

Characteristics of Case Study Region

This study was carried out in the region of Herceg Novi, Montenegro, located in the historical texture of Montenegro with traditional stone buildings and painted shuttered Windows on the edge of the Bay of Kotor. This residential area of this coastal city of Montenegro is located on the Bay of Kotor (Fig.1). It is one of the youngest cities on the Adriatic, formerly part of the Ottoman Empire and the Republic of Venice; It characterizes architecture that reflects a mix of Venetian and picturesque architectural styles (Fig.2).



Figure 1: Architectural and urban characteristic and settlement pattern of the region where the study was conducted [38].



Figure 2: The façade architecture and street façade texture characteristic of the region where the study was conducted [39].

Montenegro the Bay of Kotor region has a hot-humid climate with much more precipitation in winter than in summer. Its distinctive topography and high mountains make it one of the wettest places in Europe. This residential area is sunny about 200 days a year. Local meteorological data for this region as relative air humidity is the highest 80% indicator in autumn. It is seen in the summer period with the lowest level of 63%. The average temperature throughout the year is 15 degrees. The lowest recorded temperature (monthly average) of the studied region was measured at -1°C in January 2017, and the highest temperature (monthly average) was measured in July 2015 at 29°C. (Fig.3).

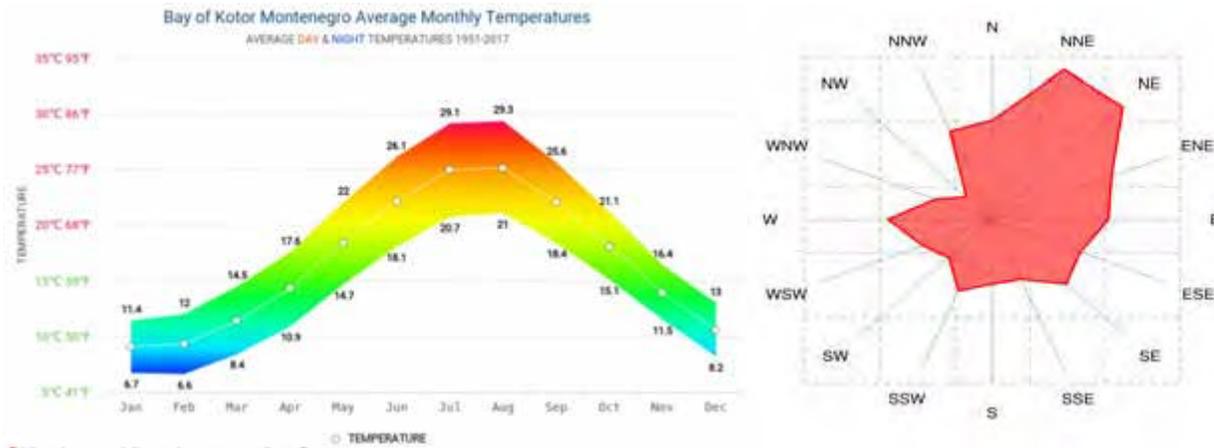


Figure 3: Meteorological measurement data of 1951-2017, average temperature values, and Wind Rose for Herceg Novi, Montenegro

Annual average local atmospheric wind conditions for Herceg Novi, Montenegro are shown in the wind rose plotted in Figure 3. It is clear that northerly winds prevail throughout the year. Also, in Table 2, maximum wind speeds are given for all directions.

Table 2: Wind Direction & Velocities for Montenegro

| Direction | N | NNE | NE | ENE | E | ESE | SE | SSE | S | SSW | SW | WSW | W | WNW | NW | NNW |
|-----------------------------|------|------|----|-----|------|------|----|-----|----|------|----|------|----|-----|----|-----|
| Maximum Wind Velocity (m/s) | 18.7 | 30.5 | 30 | 21 | 18.9 | 15.5 | 17 | 12 | 12 | 14.4 | 10 | 12.3 | 17 | 10 | 6 | 18 |

Herceg Novi, Montenegro, the case study area located in the heart of Boka Bay, is close to the two historic medieval towns of Perast and Kotor and the Adriatic Coast. The area of Kotor has been classified as a UNESCO World Heritage Site since 1979 due to its historical and cultural significance.

METHODOLOGY AND NUMERICAL MODELLING

CFD software is the most popular of the tools used to calculate the wind flow to balance the microclimate within the built environment in the urban texture. These allow easy understanding and interpretation of the flow characteristics of the wind around buildings in any urban area. For urban designers and architects, the wind flow velocity and pressure values obtained as a result of CFD analysis during the design process are used to optimize the urban texture draft project in terms of layout approaches, location, and orientation of buildings to provide the correct microclimate. It also facilitates the detailed evaluation of the comfort conditions in the texture and the wind comfort condition for pedestrians.

In this study, CFD Fluent was preferred to simulate pedestrian level comfort conditions and wind condition environments due to both the bureaucratic and economic constraints encountered for field measurements and the more comprehensive analysis parameters provided by numerical simulation. The CFD simulations were performed using CFD code Fluent and the 3D steady RANS equations. The closure was provided by the realizable (k-ε) turbulence model. The choice of this turbulence model was based on recommendations by [14] and earlier validation studies for pedestrian-level wind conditions [13]. Sensible modeling of the atmospheric boundary layer in CFD is one of the most important criteria in external aerodynamic analyzes around the

building. Many of the analysis software conduct flow analysis for materials with a low roughness coefficient, and therefore the roughness coefficient is defined as 0 in the CFD. Depending on the region where the structure is located, the roughness coefficient should also be defined. Since it is an open zone surface, the surface roughness is defined as 0.2 m [40].

Pressure differences occur on the surfaces of buildings exposed to wind. Due to the pressure difference in the building envelope caused by the wind and the density difference between the indoor and outdoor air, it causes air exchange around the building and in the buildings. Pressure coefficients largely depend on the shape of the buildings and the influence of neighboring buildings. The pressure field in a complex urban area can be analyzed to reveal the potential for natural ventilation in the urban texture. Modeling of wind flow and velocity around buildings in urban texture has traditionally been applied with full-scale measurements and wind tunnel tests when studies in the literature are examined. However, the creation and adaptation of atmospheric flow conditions in wind tunnel tests is a serious problem. Numerical simulations based on CFD are quite common as a tool to support the assessment of airflow around buildings in urban texture. CFD solves the problem of establishing and adapting atmospheric flow conditions encountered in a wind tunnel by providing both the actual wind flow velocity of the study area and the distribution of turbulence over the entire study area. The case study area of wind modeling, which takes into account regional terrain conditions and meteorological period average data of the region, includes surface roughness modeling in an atmospheric boundary layer [41,42,43].

Although RANS remains very popular in research projects, especially in the areas of wind flow and comfort between buildings, urban air pollutants and pollution dispersion, urban thermal performance, urban natural ventilation, and indoor airflow, the application of the Large Eddy Simulation (LES) technique gives an opportunity to take into account the characteristics of the wind at the atmospheric scale. The LES provides a deeper insight into the unstable flow properties. Many situations that are interesting for urban planning applications still seem to be beyond the reach of such simulations today[43].

Pressure fluctuations occurring on building surfaces depending on the average wind speed lead to both laminar and turbulent flow through leaks from the surface and between buildings [44]. High-frequency fluctuations around buildings create a turbulent distribution of air across inter-building openings containing eddies of similar or smaller size. The frequency-domain analysis of wind speed and wind pressure on the building facades is effective on the rate and amount of air exchange.

Wind-induced air change rate ACH (1/h) is given by the following equation.

$$ACH_d(t) = \left(\frac{3600}{V}\right) \sum_{j=1}^n (K_{d,j}(Vq)) A_j \quad (\text{Eq.1})$$

$$[0.5\rho(Cp_{d,j}^{ext} - Cp_{d,j}^{int})V_d^2(t) + 0.04z_j \Delta T(t)]^{0.5} \quad (\text{Eq.2})$$

This equation describes the calculated air exchange rate for different building components that are exposed to a positive pressure difference or a negative pressure difference caused by the wind blowing from d at time t.

$K_{d,j}$ in the formula; a leakage function presented as a linear function of Vq regarding the flow rate from the building openings to the area of the building component j and the corresponding pressure drop across the openings for the wind blowing from there, $d()$; vq – “frictionless flow rate” (m/s) through openings; n - the number of elements of the building envelope facing only positive or only negative pressure difference; V – volume (m³); A_j – area of j-th element (m²); ρ air density (kg/m³); $Cp_{d,j}^{ext}$ – assumed external pressure coefficient (-) for facade j exposed to wind from direction d; $Cp_{d,j}^{int}$ – assumed internal pressure coefficient for facade j exposed to wind from direction d (-); $v_d(t)$ – wind blowing from direction d (m/s); z_j – the vertical distance from the neutral pressure layer to the center of the j-th building element (m); $\Delta T(t)$ – 10-min mean temperature difference between outside and inside (K) treated later on as slowly changing one-hour mean.

Pressure differences and fluctuations in wind flow caused by turbulence around buildings have an effect on airflow through openings and cracks in the building envelope and between buildings. The character of the wind flow depends on the scale of the wind flow length and the geometrical properties of buildings and their cracks in relation to the Reynolds number for airflow[45,46].

COMPUTATIONAL DOMAIN SETTINGS-PARAMETERS AND MESHING SYSTEM

A solid model of the case study area was created with the information obtained from the 2-D architectural project and site plans of the buildings. Three dimensional model of the project is illustrated in Figure 5. The definition of wind direction is illustrated in Figure 3. The CFD model represents buildings set along with the real topography of their location. The 1000 m X 1000 m topography where the case study buildings are situated has been obtained from the Google Earth software For the atmospheric boundary layer to be formed correctly, a denser grid was used in regions with rapid changes in geometry and near the surface. As a result, the quality of the grid has an effect on the precision when the results are compared with the experimental values. Using the grid tuning twice during the analysis caused the grid to become denser where necessary and the flow solution to converge in the continuous flow regime. It was applied automatically in every 300 iterations depending on the average pressure changes on the predetermined surfaces in the buildings. The design of buildings must account for wind loads, and these are affected by wind gradients. The respective gradient levels, usually assumed in the Building Codes, are 500 m for cities, 400m for suburbs, and 300 m for flat open terrain [47].

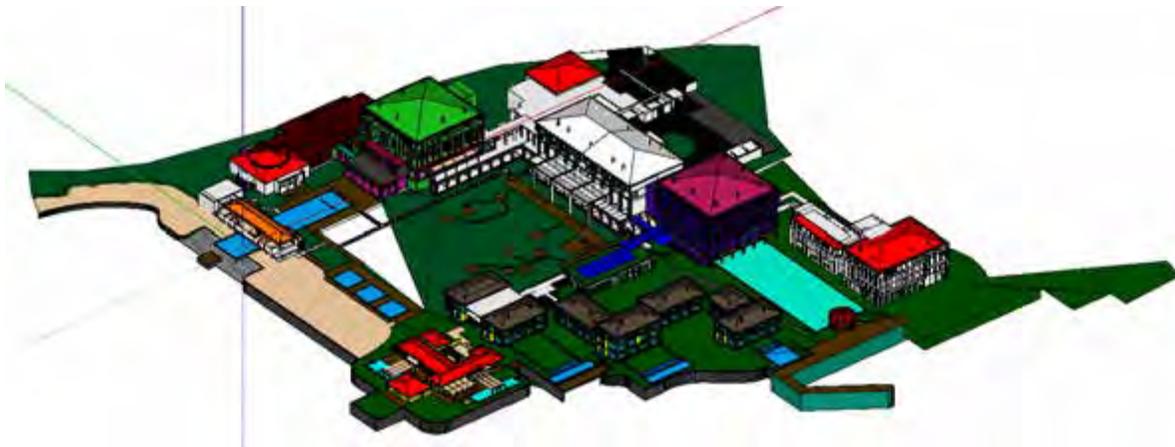


Figure 4 . 3D model view of the case study

The approaching wind was created from a power-law model to approximate the mean velocity profile:

$$U = U_r + \left(\frac{Z - d}{Z_r} \right)^\alpha \quad (1)$$

Where; U = mean wind speed, Z_r = reference height, U_r = wind speed at reference height Z_r , d = zero plane displacement, and α = power-law exponent. The exponent α varies according to the type of terrain; α = 0.14, 0.25, and 0.33 for open country, suburban and urban exposures respectively. At the inlet condition, the power-law equation is used to simulate a mean wind velocity of 30.5 m/s at the building height according to an exponent α , which is, depends upon the surface roughness of the terrain surrounding the building model. The input parameters for wind density, ρ , and wind dynamic viscosity, η are based on the real wind characteristic.

Mean wind velocity 30.5 m/s was used as inlet boundary conditions at 10 directions. 30.5 m/s maximum wind velocity was used as inlet boundary conditions at 10 directions as shown in Table 1. So that the worst scenarios were considered.

The accuracy of simulation results is highly dependent on the appropriate computational modeling, such as domain size, grid size, and grid discrepancy. Therefore, the CFD simulation modeling for the validation approach discussed in this study complies with the AIJ (Architectural Institute of Japan) guidelines, which is one of the standards in the literature for the urban pedestrian wind environment. AIJ guidelines are based on a series of cross-comparisons between CFD, wind tunnel experiments, and field measurements. In contrast, another popular guideline, Cost recommendations, is based on a literature review [48]. The calculation area size for the validation experiment is 500 m x 500 m x 50 m ($W \times L \times H$). The domain is divided

into 125,170 grid points. Pressure velocity coupling was taken care of by the Simple algorithm. Second-order discretization schemes were used for viscous terms of the governing equations. Simulations were performed for ten wind directions as seen in Table 3. The iterations were terminated when the scaled residuals showed a very little further reduction with an increasing number of iterations. The following minimum values were reached:

For x, y, z-velocity components: 10^{-8} . For $(k - \epsilon)$: 10^{-7} . For continuity: 10^{-6}

Table 3: Power Law Exponents for Various Descriptions of Terrain

| Description of the Terrain | Power Law Exponent, a | Gradient Height, Z_g |
|---|-----------------------|------------------------|
| For open country, flat coastal belts, small islands situated in large bodies of water, prairie grasslands, tundra, etc. | (0.14) | 900 ft (274 m) |
| For wooded countryside, parkland, towns, outskirts of large cities, rough coastal belts | (0.29) | 1,300 ft (396 m) |
| For centres of large cities | (0.40) | 1,700 ft (518 m) |

Four layers (layer height: 0.5 m) are arranged below the assessment height (2.25 m above ground) to comply with AIJ guidelines. In the first step, a flow volume is created around the buildings. This area is called the computational area. This area is knitted with the network structure while creating the mathematical model. Then, boundary conditions are defined. After these definitions are made, the equations are solved and the result is reached. In all simulations, a denser network structure has been created in areas where velocity and pressure gradients are predicted to be high.

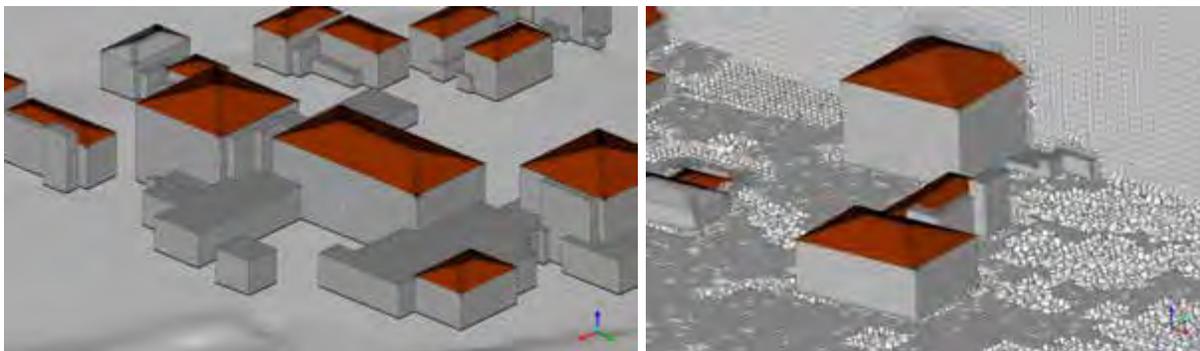


Figure 5. Computational domain mesh numerical grid system

The first step is to discretize a part of the continuous space around the considered building. This part of space is named the computational domain. The domain was divided into a finite volume. For each volume of the computational domain, the basic equations were set up. Subsequently, the equations are solved given a set of initial and boundary conditions. For all performed simulations a mesh is used which is denser in regions where velocity gradients or pressure gradients will be high. An example of the mesh used is illustrated in figure Figure 5. The computational domain mesh consisted of about 12 million polyhedral and hexahedral cells.

RESULTS AND DISCUSSION

Pressure differences occur on the surfaces of buildings exposed to wind. Due to the pressure difference in the building envelope caused by the wind and the density difference between the indoor and outdoor air, it causes air exchange in/around the buildings. Evaluation of the effect of wind on the air exchange rate is generally limited to analysis of hourly average wind speed. The wind pressure and the pressure coefficient in the leeward area mostly depend on the form characteristics of the building according to the wind direction. The frequency-domain analysis of wind speed and wind pressure on the building facades is effective on the rate and amount of air exchange. Thus, due to the changing rate and amount of air exchange around the building, the amount of air exchange around the building will vary in the urban texture, and both the urban air quality and the pedestrian level will be effective on microclimatic comfort values. Air exchange in buildings and around the buildings is caused by the pressure difference in the building envelope caused by the wind and the density difference between the outside and indoor air. So, the

minimum and maximum wind pressure difference on buildings cause air exchange around and inside the building [46]. For this reason, in this study, the minimum and maximum pressure values that affect the amount of air exchange around the buildings in the urban texture were examined. Evaluation of the effect of wind on the air exchange rate is generally limited to analysis of hourly average wind speed.

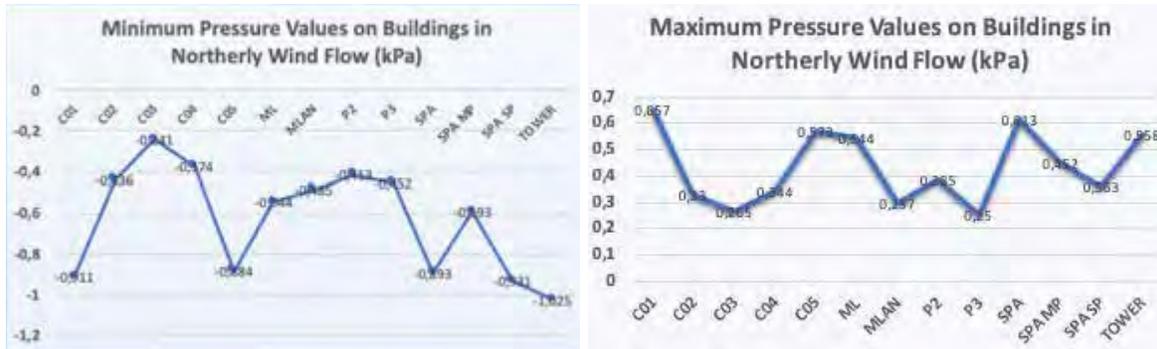


Figure 6: Maximum & Minimum Pressure on Building Facades for Wind Direction: North (N)

It was observed that the region with the highest pressure difference occurred in the region where the C01-C05-SPA buildings and TOWER buildings are located (Fig.6-7). In the case of northerly wind flow, the highest air exchange rate between buildings was observed in the region where the C01-C05-SPA-TOWER buildings are located. When the ACH around the buildings is evaluated according to the ΔC_p values in Table 1, it is seen that it is an enough and good level in the regions where there are other building groups other than the building groups where the lowest and highest pressure differences are seen.

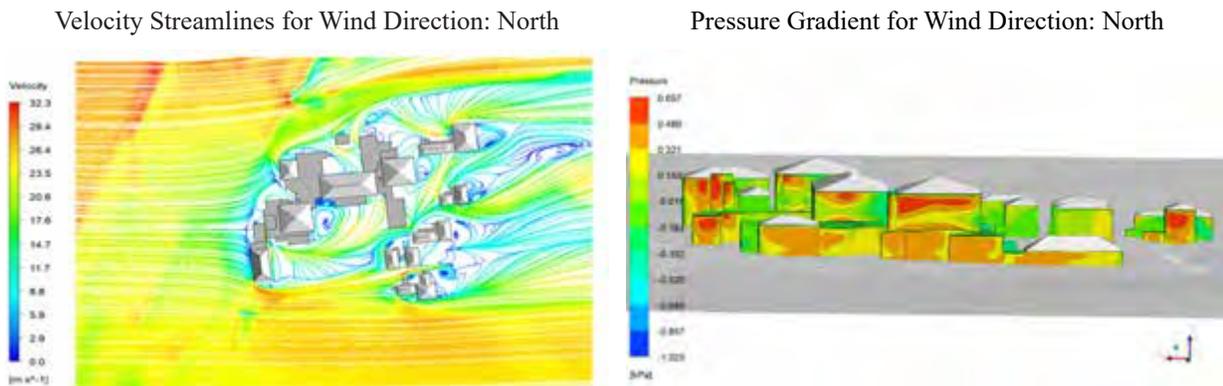


Figure 7: Velocity Streamlines and Pressure Gradient for Wind Direction: North (N)

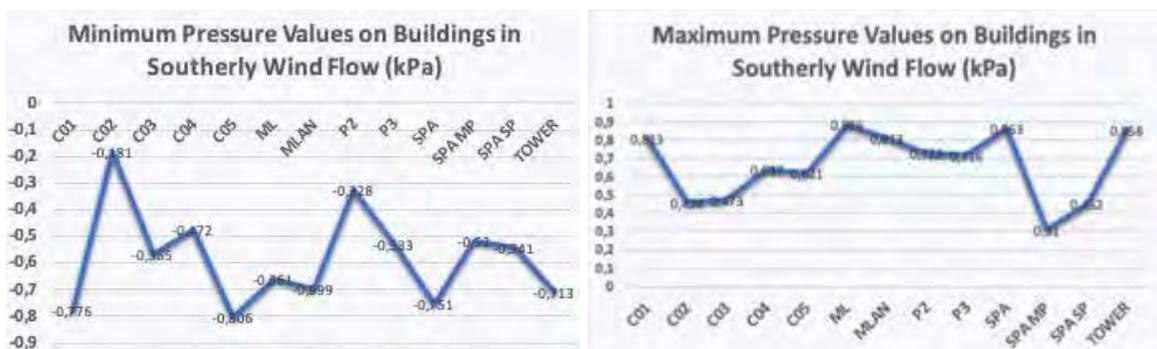
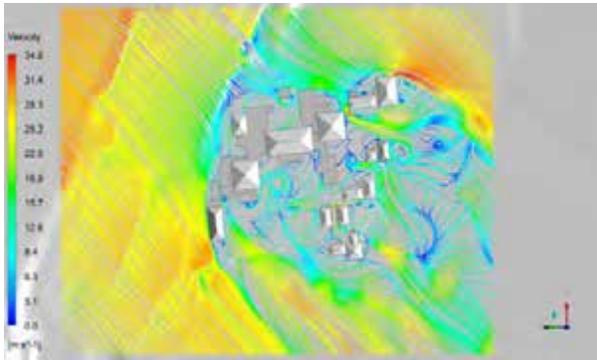


Figure 8: Maximum & Minimum Pressure on Building Facades for Wind Direction: South (S)

It was observed that the region with the highest pressure difference occurred in the region where the C01-C05-SPA buildings are located (Fig.8-9). In the case of southerly wind flow, the highest air exchange rate between buildings was observed in the region where the C01-C05-SPA is located.

Velocity Streamlines for Wind Direction: South



Pressure Gradient for Wind Direction: South

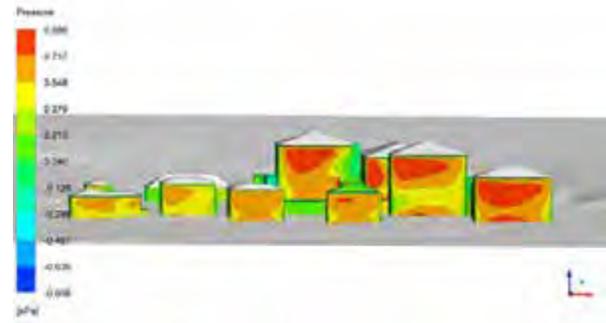


Figure 9: Velocity Streamlines and Pressure Gradient for Wind Direction: South (S)

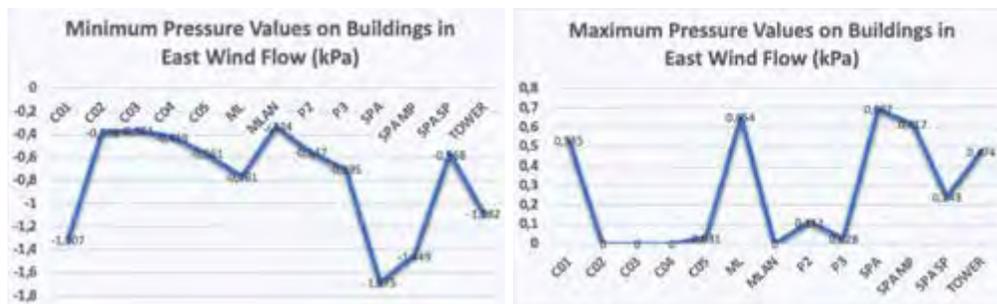
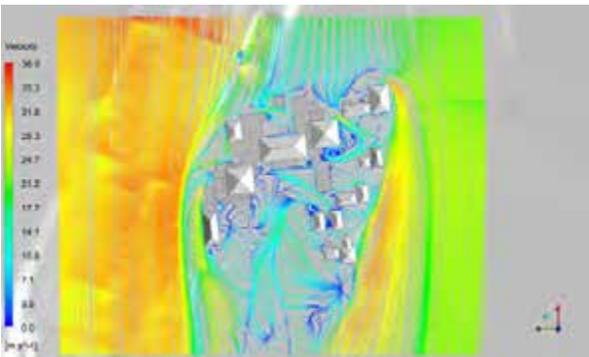


Figure 10: Maximum & Minimum Pressure on Building Facades for Wind Direction: East (E)

It was observed that the region with the highest pressure difference occurred in the region where the C01-ML-SPA-MP buildings are located (Fig.10-11). In the case of east wind flow, the highest air exchange rate between buildings was observed in the region where the C01-ML-SPA-MP are located.

Velocity Streamlines for Wind Direction: East



Pressure Gradient for Wind Direction: East

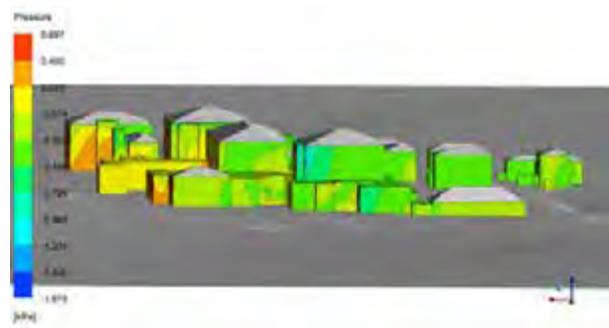


Figure 11: Velocity Streamlines and Pressure Gradient for Wind Direction: East (E)

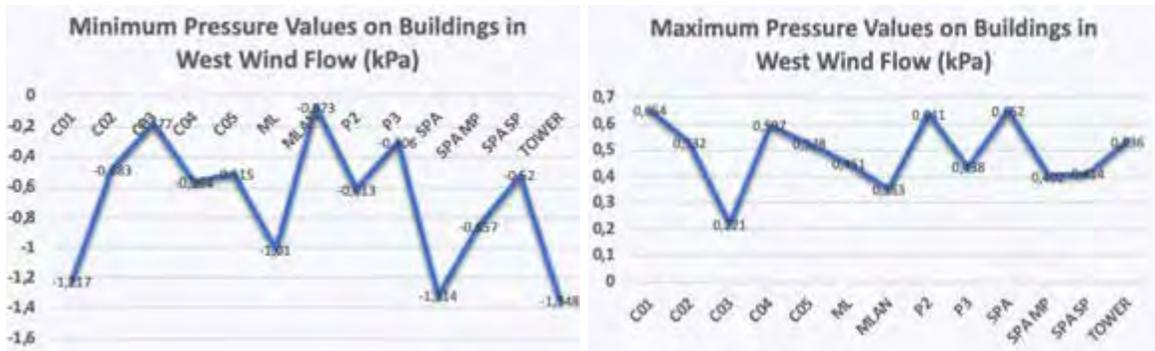
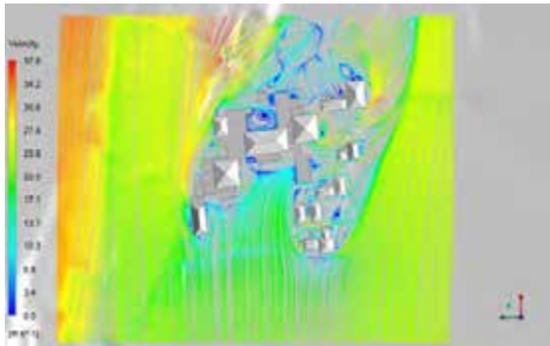


Figure 12: Maximum & Minimum Pressure on Building Facades for Wind Direction: West (W)

It was observed that the region with the highest pressure difference occurred in the region where the C01-C04-ML-P2-SPA buildings are located (Fig.12-13). In the case of West wind flow, the highest air exchange rate between buildings was observed in the region where the C01-C04-ML-P2-SPA buildings are located.

Velocity Streamlines for Wind Direction: West



Pressure Gradient for Wind Direction: West

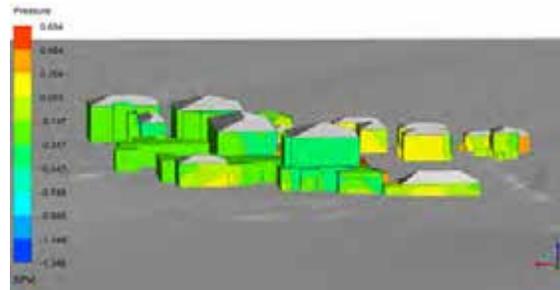


Figure 13: Velocity Streamlines and Pressure Gradient for Wind Direction: West (W)

In this study, a total of ten wind directions, four cardinal directions, and six intercardinal directions were discussed on the settlement pattern in the historical Montenegro region, which was considered as a case study. In this paper, the results of four main directions and four intermediate directions are evaluated in detail. Air exchange in and around buildings is caused by the pressure difference of the wind on the building envelope and the density difference between the outside and indoor air. Therefore, in this study, pressure differences on buildings, which are one of the sources of air changes occurring around the building, are discussed in detail. In this context, the wind directions that cause the most air change on the buildings in the urban texture, which is considered first, are the wind flows coming from the NE and NNE directions.

According to the relationship between the rates of change in the surface pressure differences of the buildings and the air variability between the buildings, the data obtained as a result of the analyzes were examined in detail, it was observed that the C01-C05-ML buildings were the building group with the highest pressure difference and showing similar characteristics in all wind directions. The positive wind pressure is the pressure acting towards the wall, whereas the negative pressure/suction is the pressure acting away from the wall of models. From the pressure contours, it can be observed that on the windward face a positive pressure distribution is observed. The maximum positive pressure is 0,75 kPa at the C01 building on the NNE-ENE wind direction. Maximum negative pressures (suction pressures) occurred mostly at the ridges and edges of buildings as shown from pressure gradient results.

The wind load also varies between points on the building envelope, with ridges, corners, and edges most susceptible to high wind pressures. These locations are likely to require careful detailing.

When the ACH around the buildings is evaluated according to the ΔC_p values in Table 1, it is seen that it is an enough and good level in the regions where there are other building groups other than the building groups where the lowest and highest pressure differences are seen.

When the results of the analyzes on all prevailing wind directions and flows are examined in detail, building layouts can be revised and optimized to allow sufficient pressure on the facades of buildings with the lowest pressure values around each group of buildings. Otherwise, buildings with insufficient wind flow and therefore buildings with low-pressure values will be exposed the insufficient natural ventilation performance.

CONCLUSION

The paper focused on a numerical methodology to assess the effect of building orientation and forms, and street orientations in terms of pedestrian level microclimatic comfort and natural ventilation of pedestrian level comfort conditions in historical urban texture within the dense structure of the city of the case study area, which is located in the historical texture of Montenegro region. The microclimatic conditions around the buildings in the urban texture depend on the layout design decisions of the buildings forming the texture and accordingly the actual wind condition conditions between the buildings. The actual wind condition is the result of the interaction of all kinds of ground obstacles around the buildings with the wind as well as the coming together of the buildings. It depends on the wind speed and direction at different levels from the ground and the shape of the obstacles (architectural form, physical plan), building airtightness (or permeability), and the position of adjacent buildings relative to each other (urban plan).

Making the design suitable for the microclimate in the urban texture; can be achieved by analyzing the wind speed and pressure differences between the buildings, choosing the appropriate place according to the natural morphology of the land, consciously designing the form of the building, placing the adjacent buildings and arranging the distances between them correctly. The results obtained in the case study in question showed that; it has been observed that the desired air flows are obtained even at very high wind speed in the areas between buildings, with the effect of the correct settlement in the urban texture and the correct spaces left between the buildings.

Consequently, architects and urban planners need to use wind and comfort analysis software effectively in the design process in line with microclimatic comfort and sustainable urban planning sensitivity, both when making settlement decisions in historical texture and when making urban design and building architectural project design decisions in open land.

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LIFE-COMP0LIVE: NEW GENERATION OF BIOCOMPOSITES BASED ON OLIVE FIBERS FOR INDUSTRIAL APPLICATIONS. FIRST RESULTS

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ABSTRACT

The project LIFE COMP0LIVE (LIFE18 ENV/ES/000309) aims for the revalorization of the pruning waste into new biocomposites (polymer matrix plus olive fiber) for both automotive and, urban and house furniture sectors. It follows a Circular Economy strategy, highlighting a double benefit in terms of environmental effects, avoiding (i) the burning of the residues and (ii) the use of fossil fuel raw materials to produce the composites for industrial uses. Olive farmers are expected to be aware of the valorization of olive waste. Moreover, policy makers and public administrations are expected to stimulate the valorization of this olive waste through regulations. The consortium is coordinated by Andaltec Plastic Technological Centre (Spain), and is formed by Caliplast and Plasturgia (France), Ford Werke GmbH (Germany), and the Spanish partners: University of Jaén (UJA), Citoliva, and Matricería Peña. This project is funded by the EASME (European Commission), in the frame of LIFE projects, and takes place in the period 2019-2023. Firstly, the type of olive fiber was conditioned in terms of size. Secondly, polymer matrices were selected to be according to recyclability, industrial applications and end users' requirements. Thirdly, different fiber chemical treatments were performed for an optimized coupling between fiber and polymer matrix. Treatments were optimized in terms of temperature, reagents concentration and reaction time. Fourthly, biocomposites were fabricated. Sixthly, their characterization allowed to obtain the optimum treatment (response surface) based on the mechanical requirements. Seventhly, the scaling-up of the chemical treatment of the olive fiber and biocomposite manufacturing process are in progress.

KEYWORDS

Biocomposites; Olive pruning; Olive fiber; Natural reinforced polymer composites; Circular economy

INTRODUCTION

The European Union is committed to a sustainable bioeconomy, which can be defined as the group of economic activities aimed at obtaining products and services that generate economic value while using resources of biological origin as raw material and that turn out to be a viable alternative. In this way, the current economies could be steered in a direction that allows for greater sustainability in the use of natural resources, both in agriculture and industry, and economic growth.

The total amount of olive trees cultivated in the world is more than 1500 million olive trees, while olive tree crops cover a total of 11 million hectares around the world, with an increase of around 150 000 ha every year. More than 50 countries in the world produce olive oil, including non-Mediterranean countries as Finland, China, or Australia [1]. In spite of the great extension of olive tree crops, 80% of olive tree plantations corresponds to Mediterranean regions. Moreover, five countries produce 70% of the world olive oil production (ranked in order of highest to lowest production): Spain, Italy, Greece, Tunisia and Morocco.

More than 8 million tons of olive pruning are generated every year in the European Mediterranean countries. To have an idea of the quantity of olive pruning waste, this can be compared to the consumption of furniture in the European Union (EU), which is around 10.5 million tons per year [2]. The highest concentration of olive tree plantations takes place in the Spanish province of Jaén, with more than 590 000 ha of the total province area (1.35 Mha), with an olive oil production of around 40% of the total Spanish production. Olive pruning is the main agricultural residue in this region and may be understood as a risk for the agricultural activity itself.



Figure 1. (Left) Olive tree grove. (Center) Olive pruning accumulated on the ground. (Right) Typical burning of olive pruning in an olive grove area.

Olive pruning waste is typically either shredded and deposited on the soil among the olive trees or burnt in fields. If the pruning is shredded in the fields it can serve as a source of nutrients for soil. However, this consumes energy and has a cost for farmers. In addition, the carbon fixed in the olive pruning can be emitted to the atmosphere more rapidly than in the case of using olive pruning as reinforcement in biocomposites.

Moreover, excessive olive pruning in fields may be detrimental due to pest propagation. In the case of the stubble burning, this represents a source of pollutants (CO, NO, SO_x, dioxins, particulate matter, soot, etc.) that can affect the surrounding areas and population near the olive trees plantations, moreover, the burning produces GHG emissions (Fig. 1). It also supposes a risk of fire spreading.

Potential ways of utilization of olive pruning can be through the thermochemical route (dry) or through the biochemical route. The thermochemical route can be through combustion, pyrolysis, gasification or liquefaction. The biochemical route can be through methanation or through hydrolysis and fermentation [3]. However, none of these routes is actually implemented.

In addition, the utilization of olive fiber from pruning residue as reinforcement for polymer materials is a way of utilization that has not been developed to date. In the case of using the olive pruning to obtain wooden fiber to be used in a composite, some advantages arise. First, most of the carbon present in the olive pruning will remain in the olive fiber and its incorporation into the atmosphere is delayed. Second, since the pruning is not burnt, the correspondent pollutant emissions are avoided. Third, instead of being a cost for farmers, the use of the olive pruning residues in biocomposites can be an economic outcome for farmers. Moreover, if the olive pruning processing plants are near the olive crops –which is the most expectable situation–, some jobs could be created in those rural areas, and therefore, a new business model could be established in rural areas.

For all these reasons, the Project LIFE-COMPOLIVE (ref. no. LIFE18 ENV/ES/000309) aims the revalorization, at industrial scale, of the olive pruning waste as a reinforcing fiber of new biocomposites, which are based on polypropylene, PP, or on bioplastics such as poly(lactic acid), PLA. Moreover, a Circular Economy strategy is followed and a double benefit is pursued: i) to avoid the burning of pruning waste in field, and ii) to reduce the consume of fossil fuel-based raw materials (such as PP). In order to also have a more sustainable material, instead of the conventional PP, recycled PP (rPP) is used in this project.

Some advantages can be pointed out in relation to the use of the natural fiber obtained from the olive pruning. First, the olive fiber can reach a relative weight of up to around 40% of the biocomposite. This supposes a significant reduction in the use of raw materials and a reduction in the weight of a produced part, since the density of the fiber is lower than that of the polymer matrix. Thus, potential Green House Gases, GHG, emissions related to the use of a non-renewable raw material, such as non-renewable PP-based polymer matrix, are diminished. Second, natural fibers, as the olive-based ones, are biodegradable, making this biocomposite a more sustainable material [4, 5]. Moreover, this kind of material is according to the European Union's plastic strategy [6].

Due to the advantages of the use of olive fibers in biocomposites, they can be seen as a potential substitute of conventional materials in different industries, as other natural fibers-based composites [7]. Other fibers are also able to be used as reinforcement agents: hemp, sisal, jute, cotton, flax, etc. [8-12]. These natural fibers improve interesting mechanical properties for industrial applications [13].

Bearing in mind those advantages and potential impact of the use of olive fibers in biocomposites, their availability to supply industry demands is to be analyzed.

MOTIVATION AND OBJECTIVES OF THE PROJECT

The industrialization of the olive fiber-based biocomposites for three different sectors, automotive, home furniture, and urban furniture, is the main objective of the LIFE-COMPOLIVE project. These olive fibers derive from the olive pruning residue. Thus, non-renewable materials, as PP, are substituted by a renewable one (olive fibers).

The motivation of the project can be understood from different points of view, such as in relation to the legislation (use of recycled materials and the creation of new legislation), environmental (reduction of GHG emissions), Circular Economy (valorization of agricultural residue), market opportunities (creation of a new tailor-made product with no direct competitor), etc.

The need to use recycled materials is increasing. One example, in the case of the automotive industry, is the European regulation on end-of-life vehicles, contained in Directive 2000/53/EC of the European Parliament (Figure 2), which encourages the increased use of recycled materials in vehicles.

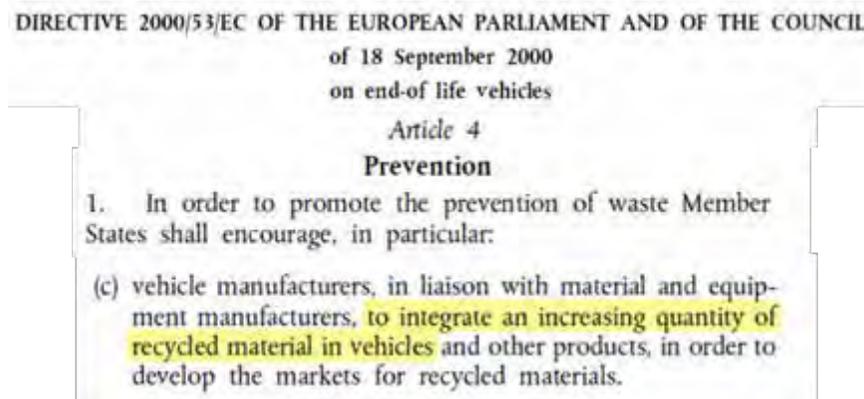


Figure 2. Extract of the Directive 2000/53/EC of the European Parliament and of the Council in relation to the end-of-life of vehicles and the recycled materials.

The concept of Circular Economy is intended to be implemented in the LIFE-COMPOLIVE project in priority sectors for the EU, ensuring the use of secondary agricultural resources within a specific value-chain or different ones. One of the main areas in the frame of the Circular Economy is focused in the creation of bio-based, sustainable and recyclable goods obtained from residues, within a cascade approach. A new value-chain will be created by means of the collection and reuse of raw material, which has been previously considered as residues, by disseminating the potential use of this bio-based product in influential sectors, such as the automotive and furniture sectors. This will support the transformation of small and medium-sized companies and integrate the social perspective in the value-chain.

From the point of view of the economic potential of this proposed solution, on one hand, the total annual quantity of olive pruning waste available ensures the supply of industrial needs in sectors such as furniture or automotive, among others. On the other hand, its market potential is huge enough to make it attractive for investors (see Figure 3). Specifically, the total addressable market (TAM) for biocomposites is estimated to be of EUR 46 400 million. Considering only the market of biocomposites in the automotive and furniture sectors, which would be the serviceable available market (SAM), it reaches EUR 4600 million. Finally, the serviceable obtainable market (SOM) for the partners of the project can rise EUR 30 million.



Figure 3. Market potential for the proposed solution in this project.

The proposed solution in this project can be related to some market opportunities, as summarized in Figure 4, and detailed in the following lines. The amount of olive groves is sufficiently large, so it is not necessary to increase the quantity of olive groves to supply the industry. Few milling system manufacturers offer those machines needed to accurately obtain the required olive fiber, which represents a market opportunity for companies. In relation to the polymer technology, the same extrusion lines used for conventional plastics can be used for this new type of biocomposites, thus no additional investment is required. In addition, the production costs of these biocomposites are not higher than that of conventional polymer. The biocomposites can be tailored to meet the different industrial requirements of each application. The technical solution proposed in the project is also the basis for new business models, based on the principles of the Circular Economy, valorizing a material currently considered as a waste.

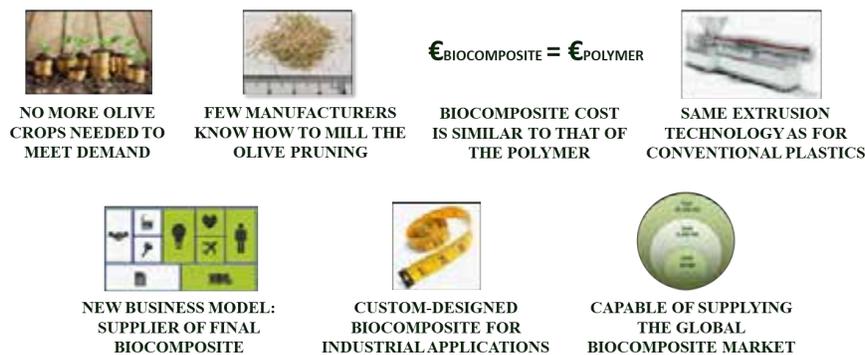


Figure 4. Summary of market opportunities related to the LIFE-COMPOLIVE project.

It is noteworthy to mention that the project has been selected by the of the European Commission’s Innovation Radar [14]. It is recognized its business readiness and that this project responds the needs of real markets and customers. In addition, the alignment of the project with the “Sustainable Development Goal 12 of United Nations: Ensure sustainable consumption and production patterns” is also recognized.

Specifically, this project aims to address five different problems by proposing the corresponding solutions and key actions to be executed. First problem, more than 7 million tons of olive pruning waste are generated each year in Europe. The proposed solution is to valorize this waste. The related key action is to demonstrate, on an industrial scale, the usefulness of the olive fiber as a polymer reinforcing agent. Second problem, a non-negligible amount of the olive pruning residue is burned in the fields every year. It is planned to demonstrate the valorization of 15 useful tons of olive fiber per year at the end of the project, incorporating it into polymer matrices up to 40 wt%. Third problem, there is a high demand for fossil-based plastics in the automotive and furniture industries. The proposal is to substitute those materials with bio-based ones, such as olive fiber. The related key action is the creation of three different business models based on the efficient management of olive pruning residues. Fourth problem, there is little concern in the primary sector regarding the use of the olive pruning residues. The proposed solution is related to the awareness and sensitivity of the primary sector through an economic and ecological management of olive grove residues. To this end, dissemination and awareness-raising activities will be performed to engage farmers. Fifth problem, there is a low political concern for the use of olive pruning residues. The proposed solution is to encourage changes in the current legislation to promote the use of the olive pruning residues. Specific activities will be carried out to involve authorities and policy makers at both national and European level. The specific objectives can be grouped as follows (Table I):

Table I: Specific Objectives of the Project

| | |
|-----------------|---|
| Environmental | <ul style="list-style-type: none"> • Revalorization of the olive pruning residue. • Production of sustainable biocomposites with a minimum of 15% in weight of fiber. |
| Techno-Economic | <ul style="list-style-type: none"> • Development of eight different biocomposites at laboratory scale plus four ones at large scale. • Scaling-up of the fabrication of the olive fiber-based biocomposites. • Fabrication of three real prototypes. • Technology transfer. |
| Social | <ul style="list-style-type: none"> • Public engagement, especially in the agricultural sector. |

The expected success of the or the project is related to three different areas: i) to the agricultural sector, by providing an economic benefit from olive pruning; ii) to the industrial sectors, offering a value proposition through the use of more sustainable materials and also complying with the requirements of the EU directives, thus ensuring continuity in the EU market; and iii) establishing the basis of a high value-added biocomposite industry, which will create local jobs for the processing of olive pruning, and design and manufacture of olive fiber-based biocomposites.

STAGES AND MAIN ACTIONS OF THE PROJECT

The project consists on different Actions. Technical Actions, from A1 to B5 can be considered as consecutive ones, while Actions C, D and E are continuously implemented along the whole project. Figure 5 shows a schema of the project's Actions. Note that the Action B2 is currently in progress.

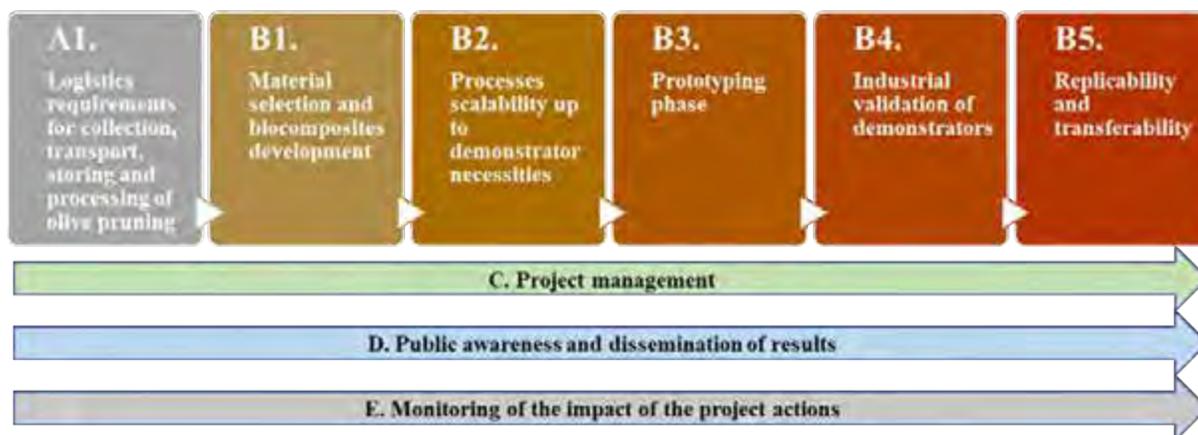


Figure 5. Actions comprising the project.

Action A1

The abundance of the olive pruning residue as a renewable resource for biocomposites in Mediterranean European regions to provide industrial needs in the automotive and furniture sectors was demonstrated. Furthermore, the logistics for collection, transportation and storage of the olive pruning were economically analyzed for the surrounding area of Andaltec. See in Fig. 6 a detail of the olive pruning at larger scale in Andaltec's facilities.



*Figure 6. Images of the olive pruning at scale of few tons.
This olive pruning was already shredded to reduce the length of the pruning sticks to 10-20 cm.*

Action B1

In the first steps, the polymer matrix and the type of olive fiber were selected to reach the technical requirements needed for the applications indicated by the end users of the Project. In relation to the selection of the olive fiber, the olive pruning waste was morphologically and chemically characterized. For an optimal coupling of the fiber with the polymer matrix, the necessity of a previous chemical treatment to the fiber arose. Polymer matrices were chosen to meet the requirements of the industrial applications, as well as to come from renewable resources and/or from recycled polymers.

After the selection of the type of olive fiber and the polymer matrix, a Design of Experiment (DOE) methodology was applied. The optimum chemical composition of the fibers was predicted and the chemical reaction parameters (temperature, reaction time and reactive concentration) were tuned to achieve the desired mechanical properties of the biocomposites. A mathematical model previously developed was used [15, 16]. The olive fiber before and after the chemical treatment can be seen in Figure 7.



*Figure 7. (Left) Olive fiber obtained from olive tree pruning.
(Center) Chemical reactor for the treatment of olive fiber. (Right) Chemically treated olive fiber.*

A series of different biocomposites were obtained after different compounding procedures between olive tree fiber and polymer matrix. Every single applied compounding process is feasible to be scaled-up, while only some of them are suitable to be manufactured through injection molding –pellets of biocomposite are obtained by using an extrusion line (Figure 8). Moreover, for some applications, recycled plastic as polymer matrix was demonstrated to meet the requirements of the industrial applications. To complete this analysis, the costs of the different obtained biocomposites were estimated.



Figure 8. (Left) Extrusion line: polymer matrix and olive fiber are mixed.
(Right) The resulting biocomposite is finally transformed into pellets.

The mechanical properties (tensile, impact and flexural behavior) of the biocomposites were characterized, as well as the thermal and structural ones by using injection molding specimens (Figure 9). Some examples of injected parts can be seen in Figure 10. The results of the DOE model were obtained from the characterization. A dataset of results was elaborated and a selection of the best biocomposites in terms of the feasibility of being used in those applications previously defined by the industrial partners. Most end user requirements were met, ensuring the continuity of the project.



Figure 9. Biocomposite samples for characterization tests. Detail of the olive fibers within the polymer matrix.

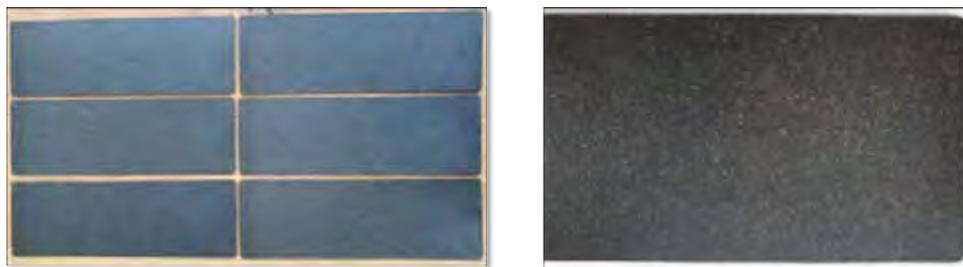


Figure 10. Samples of injected parts.

SUMMARY AND CONCLUSIONS

The project LIFE-COMP0LIVE has been presented, as well as its achievements to date. The olive fiber has been obtained from the olive pruning, chemically treated and successfully mixed with those selected polymer matrices to obtain the final biocomposites. The characteristics of the olive fiber, as well as the chemical treatment applied, have been optimized to achieve the mechanical requirements requested by the end users. The biocomposite materials were finally produced in the form of pellets, allowing the injection of test specimens for their characterization (see Figure 11). Currently, the rise to the scaling-up of production is in progress. In addition, this projects represents the basis for new value-propositions and business, based on the principles of Circular Economy.



Figure 11. Summary of the most relevant project materials.
(Left) Olive fiber. (Center) Recycled plastic. (Right) Injected characterization probes.

FUNDING

This research is funded by the European project: LIFE-COMP0LIVE (LIFE18 ENV/ES/000309), coordinated by Andaltec Technological Center.

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AGGREGATED DEMAND-SIDE FLEXIBILITY AND RENEWABLE ENERGY-BASED SUPPLY FOR THE OPTIMAL MANAGEMENT OF RENEWABLE ENERGY COMMUNITIES IN PORTUGAL

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ABSTRACT

Renewable Energy Communities are key elements to achieve climate neutrality, as they provide fertile ground for the combination of emerging energy-related technologies and user-centric energy services in distributed, flexible, and collaborative ways. Based on that, this paper formulates a novel business model for the Portuguese energy landscape that comprises the conceptualisation of optimal Renewable Energy Communities from a performance-based perspective. Namely, it proposes the use of aggregated demand-side flexibility in combination with a renewable energy-based supply within the boundaries of the low-voltage energy network – focusing on capturing and delivering value to three different stakeholders: Renewable Energy Community members, aggregators, and Transmission System Operators. This paper reviews the existing legal framework in Portugal, suggesting the appropriate policy changes for the market breakout of the proposed business model. The business model focuses on widening the access of active residential consumers in the provision of demand-side flexibility services; allowing the aggregation of small-scale flexibility; and making the minimum load mobilisation capacity cap more flexible. By doing so, the Flexigy project expects to increase system flexibility through competitiveness in the electricity markets, emphasizing on transparent and non-discriminatory integration of these new energy market players whilst meeting technological progress and contributing to climate neutrality.

KEYWORDS

peer-to-peer energy trading; demand-side flexibility; energy flexibility; energy sharing; renewable energy community; demand-response; flex-offer; business model; energy policy; regulating reserve; interruptibility contract; balancing market

INTRODUCTION

Achieving climate neutral targets to tackle climate change is requiring decisive global action and significant investment and innovation by the public and private sectors. The European Union (EU) is leading the way by committing over 1 trillion Euros in research and innovation to advance climate science, deepen the knowledge base on pathways and responses to climate change, and support behavioural transformation to reach a climate neutral and resilient society & economy by 2050 [1],[2].

The EU strategic agenda on climate neutrality can only be achieved by transforming the energy ecosystem in the coming decades towards its decarbonisation, making it more integrated, competitive, customer-centred, decentralised, sustainable, seamless, smart, secure, transparent, flexible, collaborative, fair, and inclusive than before [1],[2]. This depends on new, dynamic market arrangements and overarching changes in social practices that enables the twin green and digital transitions whilst providing new services and engaging consumers [1],[2].

A key contribution to success is using demand-side flexibility to complement a renewable energy-based supply. As advocated by the EU, the real-time monitoring and management of energy networks is key to optimise the operation of the relevant infrastructures, increase the flexibility, and integrate renewables in an efficient way that ensures cost-effectiveness and affordability, security of supply and grid stability - through solutions such as storage, demand response or flexible generation, among others [3]. Moreover, the role of citizens and communities is key to create added value from the flexibility at the appliance level for the energy grid – hence the need to foment social acceptance of new energy technologies and increase participation of consumers in energy markets, putting them at the heart of the energy transition [3].

In fact, the development of energy communities (of many configurations) should be considered paramount to achieve greater levels of grid resilience and reliability at lower financial costs, as they provide fertile ground for the combination of multiple emerging energy-related technologies (e.g., renewable energy generation, energy storage, electric vehicles, smart metering, blockchain, etc.) and user-centric energy services (e.g., peer-to-peer energy sharing, collective self-consumption, flexibility, etc.) in a distributed, flexible, and collaborative way – opening new ways of organising and managing energy networks at the local level to help maintaining the overall grid balance in the face of increasing renewables in the energy mix and the electrification of new sectors of the economy [4]. Nonetheless, the speed of development of energy communities needed for the market breakout is often hindered by resistance of many forms, such as the lack of policy backup, slow technology adoption, and weak end-user engagement [4].

From a policy perspective, many were the reforms promoted at the EU-level by the European Commission that signalled the relevance of energy communities, energy flexibility and renewable integration to fit the future energy system to better achieve the new climate neutrality goals, such as the Clean Energy for all Europeans package (a suite of European legislation [5]), which includes the Renewable Energy Directive¹, the Directive on Common Rules for the Internal Market for Electricity², and the new Regulation on the Internal Market for Electricity³, to name a few examples.

The abovementioned legislative packages allow to overcome limitations of existing rigid energy market structures, disrupting the traditional energy sector and opening numerous pathways for the emergence of innovative business models and new energy market players in the user-centric energy landscape of the future. That is because the energy ecosystem is changing the way that end-users are procuring, perceiving, and consuming energy-related products and services, and the way that many utilities and energy retailers are exploring competitive advantages to meet customers' new expectations and take advantage of demand flexibility and distributed renewable energy generation.

This paper was conceptualised against this backdrop. Namely, it aims to present the business model behind the Flexigy project⁴ - a comprehensive energy-as-a-service business model that comprises the conceptualisation of Renewable Energy Communities (RECs), within which its members can participate in the provision of different user-centric services:

¹ Directive (EU) 2018/2001 sets a binding EU-wide renewable energy target of at least 32% for 2030, including, among others, provisions for enabling Renewable Energy Communities (RECs) and self-consumption of renewable energy [6]

² Directive (EU) 2019/944 aims to create integrated competitive, consumer-centred, flexible, fair, and transparent electricity markets in the EU, outlining, among other things, the role, rights, and responsibilities of aggregators, and the concept of Citizen Energy Communities (CECs) [7]

³ Regulation (EU) 2019/943 aims to adapt the current market rules to new market realities, by removing existing regulatory barriers to demand-side flexibility, whilst empowering consumers and increasing system efficiency for its decarbonisation [8]

⁴ The Flexigy project was co-funded by the Portugal 2020 programme under the Interface Programme, and by the European Union under the European Structural and Investment Funds (FEEI) (R&TD Co-Promotion Project no. 034067; Call 03/SI/2017, SI I&DT). It was officially launched in July 2018 and is expected to be concluded in December 2021

- Collective renewable energy-based supply (i.e., peer-to-peer (P2P) energy sharing and collective self-consumption).
- Demand-side energy flexibility services.

Focus is given to the Portuguese energy policy landscape, which to date does not allow the aggregation of small-scale, demand-side flexibility offers (i.e., flex-offers), and RECs and renewable energy-based supply services are yet in very early stages of deployment due to recent deregulation [9]. In view of that, the use of demand-side flexibility to complement a renewable energy-based supply in an optimal way in the context of RECs is yet to become a reality in Portugal – and this is precisely what the Flexigy project aims to address (and what this paper aims to describe).

Note that the Flexigy business model shares many commonalities with other energy market realities at the European Union level and can, therefore, be repurposed and adapted to other State Members' contexts.

THE ENERGY POLICY LANDSCAPE IN PORTUGAL

The feasible validation of the proposed business model relies on the proper analysis of the actions required to introduce and establish RECs in Portugal (alongside collective renewable energy-based supply and demand-side flexibility services), considering the existing country-specific market and legal structures whilst envisioning the EU-wide macro-objectives for the decarbonisation of the energy sector that are yet to be fully transposed in the country. Hence, this section aims to review the existing Portuguese energy policies on these matters, followed by another section that aims to propose the appropriate policy changes to accommodate the progressive vision of the Flexigy business model.

Peer-To-Peer Energy Trading, Renewable Energy Communities, and Collective Self-Consumption in Portugal

Portugal has recently introduced major modifications in the self-consumption regime of renewable electricity, guiding it towards the facilitation of RECs, individual/collective self-consumption, and P2P energy trading [9]. This was done in the context of the transposition of the EU Renewable Energy Directive (RED II) into an enabling national regulatory framework in 2019, entitled Decree-Law No. 162/2019 [9]. As explained by Annala et al. [10], this legal transposition was carried out in a partial manner to allow the responsible executive governmental agencies to gradually improve the national legal framework in view of best practices.

In the context of the Flexigy project, the Decree-law No. 162/2019 will be validated in close association with the aggregation of small-scale, residential flex-offers to create optimal RECs (from a performance-based perspective) in Portugal.

Peer-to-peer Energy Trading

The referred Decree-Law defines P2P energy trading as the sale of renewable energy between market participants (e.g., final consumers, REC members, individual or collective self-consumers, independent producers, independent aggregators, etc.) under a contract with predetermined conditions governing the automated execution and settlement of the transaction, either directly between market participants or indirectly through a third market participant (e.g., an independent aggregator) [9].

Renewable Energy Communities

RECs are defined by Decree-Law No. 162/2019 as legal, for-profit or not-for-profit entities, based on an open and voluntary membership of its members - who may be any natural or legal person, of a public or private nature, including SMEs and municipalities [9]. Also, RECs must be autonomous from its members but effectively controlled by them, provided that [9]:

- RECs must be based on the association of members that are in geographic proximity [9];
- The renewable projects are held and developed by the REC [9];
- The main objective of the REC is to provide environmental, economic, and social benefits rather than financial profits [9].

REC members have the power to produce, consume, store, and sell renewable energy through renewable power purchase contracts, P2P energy sharing, or through all suitable energy markets, either directly or through aggregation, in a non-discriminatory manner [9]. RECs are also fully responsible for imbalances caused to the national energy grid, being responsible for settling such imbalances or for delegating it to a market participant or its designated representative [9].

Although Portugal has started taking the first steps to comply with the EU-wide provisions on energy communities, it still must be further developed to reach full maturity in this topic. At present, a handful of RECs and collective self-consumption schemes (e.g., in the forms of neighbourhoods, condominiums, private social security institutions, municipal buildings and industrial complexes) started growing across Portugal, which are awaiting the decision of the responsible executive governmental authorities to receive their formal recognition on a case-by-case basis.

Collective Self-Consumption

According to the referred Decree-Law, collective self-consumption schemes are defined as a group of at least two self-consumers that own a renewable generation unit for self-consumption and that are organised in condominiums, apartment/house blocks, neighbourhoods, or industrial/agricultural units that are in geographic proximity [9].

It also introduces a new, dully qualified entity to be appointed by the respective members of the collective self-consumption scheme, entitled Self-Consumption Management Entity (Entidade Gestora do Auto-Consumo [EGAC]), that shall legally represent them before operators and administrative entities, as well as perform the following tasks [9].

- The design and management of an internal collective self-consumption regulation that defines, at least, the access and exit requirements for new and existing members; the required deliberative majorities; the rules and respective coefficients for the sharing the renewable production among prosumers; the rules for sharing the payment of tariffs; the commercial agreement to be adopted with the surplus renewable generation; and the application of the respective revenue [9].
- The responsibility for any articulation with the grid operator (namely for the purposes of managing the energy sharing activities, the respective coefficients, and making production data available) [9].
- The responsibility for the commercial relationship with independent aggregators (if the roles of EGACs and independent aggregators are not performed by the same entity), namely for the purpose of sale of any surplus renewable generation from the collective self-consumption scheme through organised energy markets, bilateral contracting (including power purchase agreements), or peer-to-peer trading regimes [9].
- The operational management of the collective self-consumption activities; the management of any imbalances causes to the national energy grid; the management of any network access charges made by the grid operator whenever the distribution grid network is used; the management of the internal network when it exists; the connection with the distribution grid; definition of the respective representative powers; among other responsibilities [9].

All in all, the Portuguese Energy Services Regulatory Authority (ERSE) [11] provided a schematic representation of the commercial / legal interplay between the EGAC and other stakeholders involved in such activities, as presented in Fig. 1.

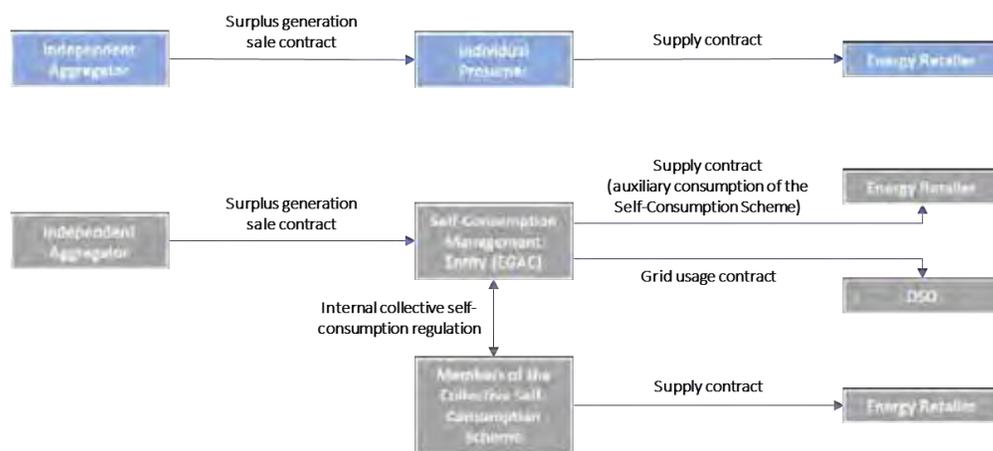


Fig 1. Schematic representation of the commercial / legal interplay between the EGAC and other stakeholders [11]

Demand-Side Flexibility in Portugal

In the thorough analysis of the different levels of maturity of demand-side flexibility⁵ among 21 EU Member States carried out by Delta-EE and SmartEn [12], Portugal was classified with a low score – which is typically represented by emerging markets that are yet not fully established and have limited demand-side flexibility activity due to this. Specifically, the aggregation of small-scale, residential flex-offers including third-party participation for the balancing market or for the provision of ancillary services is not yet possible in Portugal due to the lack of enabling regulatory frameworks. At present, only two forms of DR services are legislated in Portugal: (i) interruptibility contracts [13]; and (ii) regulation reserve services [14], which are nonetheless still subject to many restrictions [15].

The Flexigy project aims to modify the energy policies that regulate interruptibility contracts and regulation reserve services to allow the aggregation of small-scale, residential flex-offers connected to low-voltage networks, and to make the minimum load mobilisation capacity cap more flexible.

Interruptibility contracts

Interruptibility contracts refers to the voluntary reduction of the electricity consumption of large industrial consumers to a value equal or lower than the residual power in the energy grid in response to a power reduction signal given by the Transmission System Operator (TSO) [13].

However, interruptibility contracts are limited in Portugal in the sense that they exclude the participation of small-scale consumers (e.g., domestic end-users) by imposing a minimum load reduction capacity cap of 4 MW, by only accepting consumers connected to the medium- or high-voltage networks, as well as by not allowing the aggregation of flexible loads [13].

A further illustration of this limitation is that none of the 47 consumer facilities that were fully qualified to provide interruptibility services in Mainland Portugal (with a total interruptible power capacity of 1.38 GW) were ever activated by the TSO in 2020 [16]. This leads to the conclusion that interruptibility contracts are only seen as an emergency, add-on instrument for the TSO in Portugal, and not as an accessible, effective, and quick solution for the flexible management of the energy grid and the security of supply [15].

Nonetheless, this scenario changed in 2021, when a failure in the energy grid in France caused a partial blackout in Portugal and Spain - which triggered the TSO to issue an order to reduce the consumption of hydroelectric power stations with pumping and all large industrial consumers with interruptibility contracts, in addition to several consumers in the national distribution network, totalling 800 MW - half of which supplied by interruptibility contracts [17,18].

Regardless of the scenario, the Portuguese Government will terminate the operationalisation of interruptibility contracts in 2022 to give way to the Regulation Reserve Band market (*Banda de Reserva de Regulação*) [19], as the European Commission considers the former mechanism incompatible with European rules in matters of State subsidies [18]. The new mechanism for large industrial consumers represents auctions operated by ERSE (at least 10 working days prior to the date of completion) for the provision of the flexibility services at a fixed value per capacity for the balancing of the energy grid that can reach up to 20 million euros per year [19] - representing a less costly mechanism than the previous one [18].

Nonetheless, large industrial consumers in Portugal have contested the termination of interruptibility contracts, considering that the replacement mechanism will be economically less favourable to them - especially on the face of the abrupt rise in electricity prices to record levels in the Iberian market (approximately 20% higher than those in France or Germany in June 2021, who also benefits from other support to the electro-intensive sectors), as well as the rise in the carbon price (which already exceeds 50 euros per ton), calling for a clear and stable legal framework that will allow large industrial consumers to compete on an equal footing with other large industrial consumers from across different EU Member States [17]. Not only that, several EU-Member States (e.g., France and Germany) reverts much of the revenue from carbon license auctions to large industrial consumers so that they can invest in decarbonisation measures - which is not the case with Portugal [17]. In view of that, the Ministry of Environment and Climate Action in Portugal ensured that, apart from enforcing the new regime for Regulation Reserve Band services, it will also support large industrial consumers in two other ways [17]:

⁵ Across different value streams, customer segments, asset types, and market stakeholders

- To support the compensation mechanism for indirect CO₂ costs through the Environmental Fund with a value over two million euros.
- To tailor a new legal regime for the National Electric System that will also include the Statute of Electric Intensive Consumers, in which large industrial consumers will have to comply with certain obligations in return for a set of support measures for the reduction of the final electricity price paid by them.

Regulation reserve services

Regulation reserve services are characterised by an additional active power reserve that can guarantee the safe operation of the energy system in case of any imbalances between energy supply and demand, after the exhaustion of the existing reserves of primary and secondary regulations [14]. These services are provided by dully qualified energy producers who specify the available maximum active power amount that can be raised or lowered to contribute to the grid stability [14].

Until recently, the Global System Management Procedures Manual (MPGGS) that defines the rules of the regulation reserve market [14] only accepted conventional generators and pumped storage consumption units under the same Balancing Responsible Party as regulation reserve service providers (apart from the TSO). However, in 2018 ERSE launched a 1-year pilot project to trial the participation of eligible consumers in the provision of regulating reserve services, following a public consultation with different stakeholders from the energy sector, and aiming to inform the amendment of the existing regulatory framework [20].

The pilot project started in April 2019 and was concluded in March 2020 - but in view of the positive results achieved, the pilot project implementation was extended until the broader revision of the MPGGS [21].

The report that defines the rules for participation in the pilot project [20] established that the presentation of regulation reserve offers by participating consumers in the pilot project is voluntary. It also allowed the inclusion of a third party who acts as representative of participating consumers; and excluded the aggregation of consumers' facilities in the first phase of the pilot project implementation [20].

During 2019, 6 large-scale industrial consumer facilities were dully qualified to partake in the pilot project – of which only 4 presented regulation reserve offers [20]. Preliminary results indicated that all mobilisation orders were fulfilled by the participating consumers, and that they were more prone to raise their consumption rather than decrease it [20].

The analysis of good practices resulting from the implementation of the pilot project suggested the need to define, trial, and validate the roles of aggregators, Balancing Service Providers (BSPs) and Balancing Responsible Parties (BRPs) in the broader revision of the MPGGS [20].

This development of this pilot project signals a positive institutional change towards a deeper integration of renewables, demand-side flexibility and new consumers in the balancing market, the boosting of competition, and a better adaptation of the market model in favour of new market players. However, the provision of regulation reserve services in Portugal is still limited as it imposes a minimum load mobilisation capacity cap of 1 MW per consumer and restricts the participation of consumers only to those connected to the medium- or high-voltage network [14]. These criteria automatically exclude small-scale end-users from participating in the provision of regulation reserve services today, but ERSE seems to be prone to further dynamize this market in favour of aggregation and non-BRP stakeholders [20].

RATIONALE BEHIND THE FLEXIGY BUSINESS MODEL

As discussed in the previous chapter, to date there are still many shortcomings in the existing regulatory frameworks on demand-side flexibility services and RECs in Portugal. Nonetheless, considering that in 2019 the residential sector was responsible for approximately 18% of the total electricity consumption in Portugal [22], it is of utmost importance to involve the residential consumer in the provision of these services as to accommodate a more progressive vision of the user-centric energy landscape of the future.

The Flexigy project aims to address these shortcomings by proposing a comprehensive energy-as-a-service business model for the Portuguese energy sector that comprises use of demand-side flexibility to complement a renewable energy-based supply in an optimal way within RECs. Specifically, the Flexigy business model is centred around the creation of low-voltage RECs – i.e., RECs within which its members are under the same medium-voltage/low-voltage (MV/LV) transformer substation.

Considering that the median transformation capacity of MV/LV substations in urban areas is 630 kVA [23], and that the contracted power of a typical household is 6.9 kVA, the Flexigy project assumed that one MV/LV substation can accommodate approximately 90 households. Furthermore, if up to 8% of the total household contracted power within the MV/LV substation refers to flexible energy assets, each REC could offer an average of 50.4 kW in demand-side flexibility services – which could be further aggregated at higher scales (e.g., aggregation between RECs) to reach higher load mobilisation capacities.

Hence, the Flexigy project proposes the following modifications in the existing regulatory frameworks on interruptibility contracts and regulation reserve services in Portugal:

- The inclusion of domestic consumers connected to the low-voltage network in the provision of regulation reserve services and interruptibility contracts.
- The aggregation of small-scale flex-offers from RECs into a larger flexibility pool (that can be further pooled at higher scales) for the provision of these services.
- The flexibilization of the minimum load mobilisation capacity cap.

Furthermore, by deploying low-voltage REC, end-users are allowed to purchase renewable electricity at lower costs via P2P energy trading and collective self-consumption schemes, as it is locally produced and consumed within the boundaries of the MV/LV substation.

Stakeholders Involved in the Flexigy Business Model

The innovative business model proposed in the Flexigy project aims to capture and deliver added-value from the interplay between three different stakeholders in this new user-centric energy landscape (as described in Table 1 and schematised in Fig. 2):

Table 1: Description of new stakeholders in the user-centric energy landscape

| Stakeholder | | Description |
|------------------------------|--|---|
| Traditional role | New role | |
| Final consumers (end-users) | REC members | End-users belonging to the same low-voltage REC who own flexible assets (e.g., water heaters, HVAC systems, washing machines, dishwashing machines, etc.) and decentralised renewable generation units |
| Utilities / energy retailers | Independent aggregators / REC managers | Dual role that could be assumed by some utilities and energy retailers as market facilitators with balancing responsibilities who deploy and partner up with RECs to aggregate, manage, and monetise their small-scale flex-offers, whilst intermediating the peer-to-peer energy trading between its members in an optimal way |
| TSO | TSO | Flexibility buyers for tertiary reserve markets (i.e., regulation reserve services and interruptibility contracts) to secure operation of the power system, namely through requests of aggregated flexibility from RECs - which are managed, coordinated, and intermediated by the independent aggregator |

In the Flexigy business model framework, demand-side flexibility and decentralised renewable generation can be combined to suit the different needs from different stakeholders, namely:

- Comply with the TSO requests to prevent emergencies in the energy grid (i.e., regulation reserve services and interruptibility contracts).
- Compensate deviation penalties for the utility / energy retailer in wholesale markets (i.e., use of pooled demand-side flexibility to optimise offers in day-ahead, intraday, and continuous intraday markets).
- Comply with the REC members’ energy demands (i.e., activate flexibility to reduce electricity cost individually or collectively increase the use of renewables).

A schematic representation of the interplay between the different stakeholders involved in the Flexigy business model is given in Fig. 1.

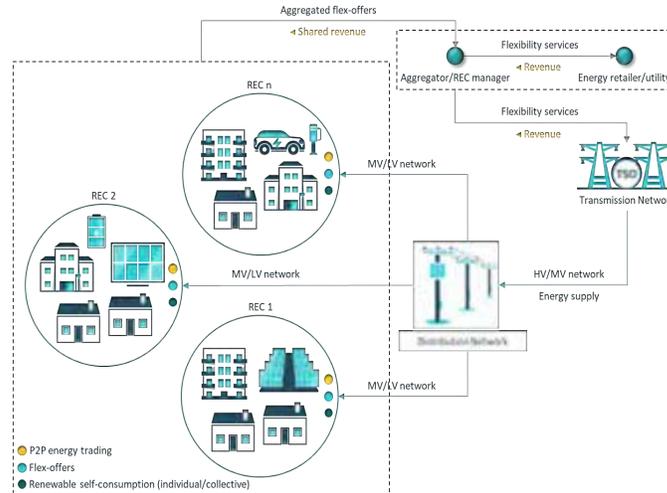


Fig. 1: Interplay between stakeholders involved in the Flexigy business model

The Flex-Offer Concept

A flex-offer is a standardised model that contains encoded information about the flexibility of domestic energy assets, either in terms of demand (e.g., electric vehicles, heat pumps, washing machines, dishwashers, HVACs, fridges, etc.) or supply (e.g., discharging stationary batteries, photovoltaic panels, etc.), in both time and amount [24]. In its simplest form, a flex-offer specifies the total power of a given equipment; the minimum and maximum flexible power that can be shifted or shed; the duration of its operation; the earlier and latest starting times; and the flexibility price, as illustrated in Fig. 2.

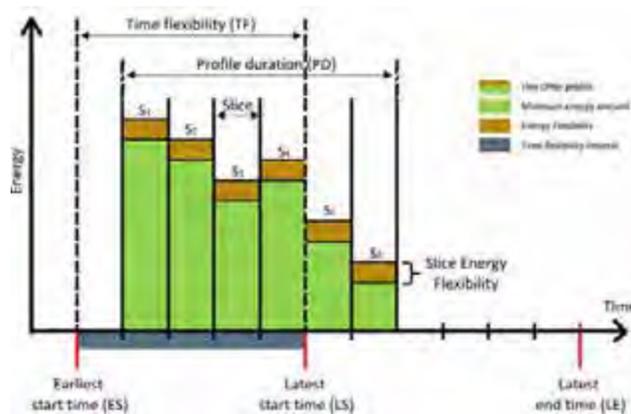


Fig. 2: Illustration of the different information encoded in a flex-offer

The flex-offer concept was originally developed by the MIRABEL project⁶ to be used under the scope of flexibility retail in energy markets and grid balancing, but this scope has been extended by the Flexigy project to also encompass energy usage optimisation (both in financial and environmental terms) at different levels (i.e., individual, community, and market levels).

Flex-Offer Scheduling Levels

The Flexigy project conceived a flex-offer scheduling algorithm to operate at three different levels, as schematised in Fig. 3. Level 1 is executed at the individual household level for the minimisation of energy costs and maximisation of individual renewable self-consumption. Level 2 is executed at the REC level for the minimisation of overall energy costs and optimisation of the renewable energy-based supply via peer-to-peer energy trading and collective renewable self-consumption. Level 3 pools small-scale flex-offers at the REC level or between RECs to respond to specific market requests from different stakeholders.

⁶ The MIRABEL project (<https://cordis.europa.eu/project/id/248195>) was funded by the FP7-ICT Programme (Collaborative Project no. 248195; Call FP7-ICT-ENERGY-2009-1). It was officially launched in January 2010 and concluded in April 2013

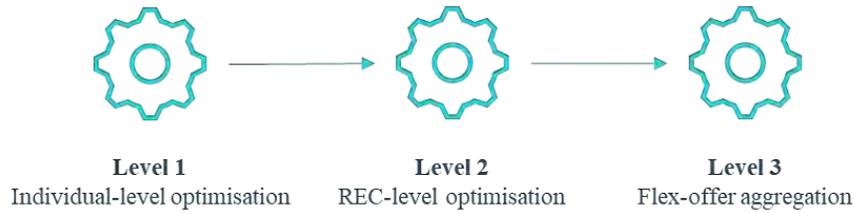


Fig. 3: Flex-offer scheduling levels

Flex-Offer Prioritisation Criteria

Since different stakeholders might request flexibility at the same time for different purposes, their requests can be complementary (in case they are in the same direction) or contradictory (in case they conflict with each other). Hence, the Flexigy business model proposed a prioritisation criteria for these requests based on their overall impact on the energy grid⁷: from this perspective, the TSO has a higher priority than energy retailers and REC members, and energy retailers have higher priority than REC members (as detailed in Table I).

Table I: Prioritisation criteria in case of contradictory requests from different stakeholders

| Stakeholder | | Service | Priority Level | | |
|---------------------------|--------------------------------------|--|----------------|--------|------|
| Traditional role | New role | | Low | Medium | High |
| TSO | TSO | Interruptibility Contracts | | | x |
| | | Regulation Reserve | | | x |
| Utility / Energy retailer | Independent aggregator / REC manager | Wholesale Energy Market Offer Optimisation | | x | |
| Final consumer (end-user) | REC member | Renewable Use Optimisation | x | | |
| | | Lower Energy Costs | x | | |

Therefore, whenever an emergency occurs in the energy grid and contradictory requests made by different stakeholders exist, the TSO request overrides all other existing requests until the grid operation becomes safe again – which should only occur on rare occasions due to its emergency nature.

In any other non-emergency situation where only complementary requests exist, these requests compete for the same available flexibility, and the biggest request is served first – e.g., in case the TSO request is higher than the energy retailer request, the energy retailer request deviates in favour of the grid balance as it is in the same direction as the TSO request.

Regardless of the case, the independent aggregator is responsible to pool the available flex-offers in a coordinated manner (within and beyond the REC boundaries, if necessary) to comply with the winning request(s).

CONCLUSIONS

This paper aims to present a novel energy-as-a-service business model for the Portuguese energy sector that comprises the conceptualisation of RECs within which its members can participate in the provision of demand-side energy flexibility services and peer-to-peer energy sharing.

The existing energy policies in the Portuguese energy landscape present major shortcomings that prevent the use of demand-side flexibility to complement a renewable energy-based supply in an optimal way in the context of RECs, and this is precisely what the Flexigy project aims to address. Specifically, it proposes the recast of the legal frameworks on interruptibility contracts and regulation reserve services, as to widen the access of active residential consumers in the provision of these services within the context of RECs; to allow the small-scale pooled demand-side participation; and to dynamize the minimum load mobilisation capacity cap. By doing so, the Flexigy project expects to increase system flexibility through competitiveness in the electricity markets, and to further incentivise joint investments in renewables through RECs, emphasizing on transparent and non-discriminatory integration of these new market players as expected by the European Commission.

⁷ This approach drew inspiration on the requirements proposed in the DOMINOES project [25]

The proposed Flexigy business model focuses on capturing and delivering value to three different stakeholders in this new user-centric energy landscape: REC members, independent aggregators/REC managers, and TSOs.

The definition of the Flexigy business model requirements is imperative to guarantee that aggregated demand-side flexibility is delivered where and when the TSOs need, helping them to better respond to unforeseen grid failures, further optimising their capacity to keep the grid stable under difficult circumstances and maintain the security of supply. Also, considering that the Flexigy business model aims to level the overall REC load distribution throughout the day, avoiding peak consumption and increasing the integration of renewable energy sources, it would consequently delay or avoid investments towards the reinforcement of energy networks.

In terms of benefits for REC members, the Flexigy business model can help them reduce their monthly energy bill by allowing the operation of their flexible assets (e.g., water heaters; HVAC systems; washing machines; dishwashers; etc.) to be shifted, increased, or curtailed in response to energy price signals or higher decentralised renewable generation and/or energy storage levels. Furthermore, they can monetise their energy flexibility by receiving financial compensation for the demand-side flexibility services provided through the aggregator according to a pre-established plan. However, if the REC member violates the execution of these services (e.g., by disconnecting the flexible asset during the agreed hours), the aggregator might apply financial penalties.

In terms of benefits for the aggregators, the Flexigy business model allows them to use demand-side flexibility to optimise their day-ahead, intraday, and continuous intraday offers in the wholesale market and consequently compensate deviation penalties, since demand-side flexibility helps reducing the volatility and uncertainty of their market decisions. Also, they can have a new revenue stream by profiting from intermediating the provision of aggregated demand-side flexibility services to TSOs.

All in all, the Flexigy project expects to encourage legislators to accelerate the recasting of existing Portuguese energy policies to accommodate a more progressive vision of the user-centric energy landscape of the future that benefits all involved stakeholders whilst meeting technological progress and contributing to climate neutrality.

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IMPLEMENTING A LOW VOLTAGE DC NANO GRID FOR A SELF SUSTAINABLE TUKTUK

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ABSTRACT

As the world's energy consumption is changing, the trend to be more self-sustainable is growing. The application of solar panels and batteries for storing energy is becoming a trend for larger mobile systems. While most sustainable energy sources produce Direct Current and most of the appliances require a DC voltage, implementing a DC nano grid would make sense. Not only as an efficient system with better control of the energy and fewer losses but also to be able to use energy as in an off-grid solution. This paper discusses all the electrical parts required for a DC nano grid that will be implemented in a self-sustainable Tuktuk. This small vehicle from ATAG Benelux has a build-in kitchen, induction hob, fridge, and LED lights, as a demonstrator for renewable energy. The electrical system has batteries and solar panels to be fully self-sustaining and an electrical hub motor implementation is considered. Solar panels will cover as much as possible surface area on top of the Tuktuk, with the option to add external solar panels and include a maximum power point tracker. The battery type and its capacity are based on experimental data from cooking tests on a custom-made ATAG DC induction hob. To power, the DC induction hob with 350VDC, a Dual Active Bridge (DAB) is considered. As a backup feature, an inverter is included to power traditional AC induction hobs. Considering the Tuk-tuk as a kitchen but also as an electrical vehicle, it needs to meet the safety requirements for both applications. The full system requirements for this off-grid DC nano grid are all simulated and assembled using in-house developed power electronics and commercially available products. Commercially available products are used to meet the regulations and safety requirements to be able to implement an operational self-sustaining Tuktuk that can be used as a demonstrator. As the electric wheel hub motor is powered from the same batteries it finally transforms the Tuktuk into a clean solar-powered electric vehicle. This will make the Tuktuk independent of fossil fuels and thus fully self-sustainable.

KEYWORDS

DC Nano Grid, Power Electronics, Self-Sustainable, Energy Distribution, Simulation

INTRODUCTION

This paper will explain how a Tuktuk, used as a food truck cooking demonstrator, is rebuilt into a self-sustainable Tuktuk. This vehicle has been upgraded with a kitchen with a gas burner to demonstrate the traditional cooking experience of ATAG[1]. With the demand for traditional gas burners decreasing, the market is shifting to induction cooking, DC-LAB and ATAG joined forces to research the possibility of a fully self-sustainable Tuktuk. To take advantage of the renewable energy sources, a DC micro grid will be implemented. This will give better control of energy and fewer losses as a system, but also makes it an off-grid solution.

The Tuktuk model from ATAG is shown in Figure 1. There are many reports on the electrification of Tuktuks, but they mainly focus only on the drive train of the Tuktuk [2]. Solar-powered vehicles are interesting in the Asian regions, for example in [3] a performance analysis of a solar-powered e-Rickshaw is reported. An onboard battery is charged during the day to increase the driving range compared to only charging during the night. The impact of the drive cycle on the drive train power consumption is reported in [4]. Also in [5], the performance of a 48 volt, 60Ah battery-powered rickshaw is reported. The power consumption for the drive train depends on the aerodynamics of the vehicle [6]. Since the rickshaw is not optimized in respect to the drag coefficient C_D , power consumption at higher speed can be excessive. The induction hob is based on a resonant power supply and is well described in the literature [7][8] The Dual Active Bridge [DAB] required to boost the battery voltage level of 48 volt towards 350 volt was first described in [9] and [10]. All of the techniques used in this Tuktuk are firstly simulated, build, and programmed with an educational power electronics tool [11] and finalized with commercially available products.

The Universal Four Leg [11], the educational tool, is used in all of the practical implementations. The sections in this paper explain how the Tuk-Tuk from ATAG has been upgraded from a natural gas- operated food truck towards a DC full electric kitchen with all the conveniences like an inductive cooking hub, lights, wall sockets, and a refrigerator. Furthermore, the Tuk-Tuk has been made self-sustainable by adding solar panels and internal storage in lead-acid batteries. Each component is described and where applicable, simulation results of the prototyping of the component are given.



Fig. 1: Concept of the self-sustainable Tuktuk.

The used voltage levels applied inside the vehicle are explained in section II. In section III the implementation and simulations of the DC nano grid are described. In Section IV the solar panels and the maximum power tracker are explained. Section V shows the batteries used for storing the power from the solar panels. The DC/DC converter for boosting the 48v DC grid to a 350v DC grid is shown in Section VI. Followed by the DC induction hob in Section VII. Protection against earth leakage is discussed in section VIII where an isolation monitoring device is used. The Electrification of the drive train by adding a brushless DC wheel hub motor with inverter and control is explained in Section IX. The final results are shown in Section X.

DC GRID VOLTAGE AND CURRENT LEVELS

For the implementation of a DC-nano grid, we need to take a look at this system as a decentralized power system. One Tuktuk can represent a household and can both consume and produce energy. In this decentralized power system, energy can be shared over the appliances inside this household. Multiple households can act as a DC-microgrid where energy can be regulated between multiple sources making them prosumers [12]. Before connecting all of these prosumers to the same DC bus, we first need to take a look inside the Tuktuk and see what kind of voltage levels are required for each appliance. Following the Dutch practical guidelines, the NPR9090[13], a DC-grid can be divided in different DC-Zones. In Figure 2, an overview of these DC-Zones is given. The Tuktuk is a protected energy source, and therefore not placed in DC-Zone 0. With batteries inside the Tuktuk, there is a possible high short circuit current possible, which makes it a DC-Zone 1 installation. With solar panels including a controlled output, we have a source with a low short-circuit current and therefore also a DC-Zone 2 installation. DC-Zone 3 & 4 are both based on protection and controlled by the semiconductors. The combination of all the appliances and energy sources makes the installation a combined installation of DC-Zone 1,2,3,4.

On the left side in Figure 3 we see where in the Tuktuk we need the power for the appliances and we can divide that into multiple DC voltage levels. An additional inverter is connected to the AC grid, in case energy needs to be shared with the AC grid or to fast charge the TukTuk if there is a lack of renewable energy.



Fig. 2: DC-Zones as defined in the NPR9090[13].

On the right side in Figure 3 the structure of the DC grid is shown. In color, the different nominal DC voltage levels[14] are displayed. The main DC grid is the 48-volt level (**gold**) where most appliances are connected. From the 48 volt DC grid, a 12 volt grid (**orange**) is created for the auxiliary loads like lighting inside the food truck and the default loads in the Tuk-Tuk like the head, brake, rear, and blinking lights as well as the car radio. Also, a conventional 12volt refrigerator for mobile homes is fed from the 12 volt supply. The 48 volt grid is boosted towards a DC 350 volt (**blue**) level for supplying the inductive cooking hub and an AC 230 Volt/50Hz outlet (**gray**) for connecting AC appliances. The solar panels (**green**) are connected via a boost converter with a maximum power point tracker to the 48 volt grid.

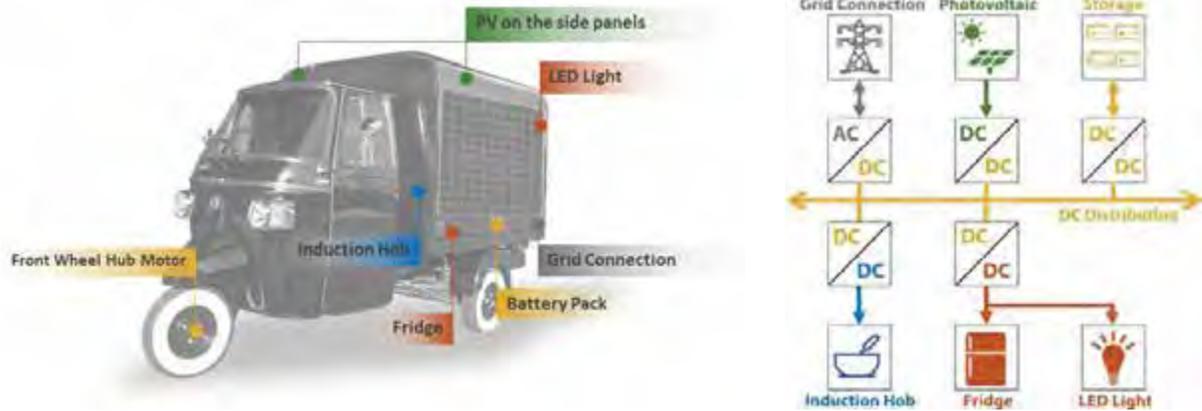


Fig. 3: DC nanogrid implementation Tuktuk divided in voltage levels for the appliances.

SIMULATING AND IMPLEMENTATION DC NANO GRID

While the DC-Zones are known and defined by now, the technical aspect needs to be discussed to realize a DC microgrid. Besides DC/DC converters to create the right voltage levels, also the application and components needed to be defined. A half-bridge topology is the best controllable and universal topology to use as DC/DC converter. Therefore multiple half bridge converters with their algorithm can increase (*boost*) voltage levels and decrease (*buck*) voltage levels. With two sources connected to a half-bridge converter, it can even act as a bidirectional buck-boost- converter. Most appliances in the Tuktuk can be recreated or controlled with these DC/DC converters. DC/DC converters control the flow of energy, the Universal Four Leg [U4L][10], is used as an educational power electronics tool to do this. This allows to fully test algorithms, in a practical setup, it is also possible to measure the control signals and plot data like the voltage and current. The setup can be programmed with an Arduino Nano and depending on the code shift between multiple DC voltage levels, to power the appliances depending on their power rating. An U4L shows a practical implementation of a DC nano grid. Before all DC/DC converters get connected to the same DC nano grid, simulation models of the U4L help to get a better understanding. The models are available on CASPOC[15]. On the left side of Figure 4 we see the CASPOC model and on the right side the U4L hardware trainer.

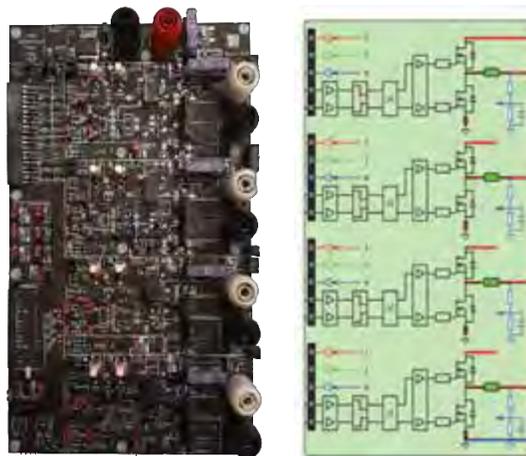


Fig. 4: The Universal Four Leg, simulation model[14] and the educative hardware trainer [10].

SOLAR PANELS AND MAXIMUM POWER POINT TRACKING

To make the TukTuk self-sustainable, solar panels will be mounted on side of the TukTuk. The TukTuk has two big surface areas where solar panels can be mounted, both of the ‘wings’ of the TukTuk. These wings can be opened, which will then point directly towards the sky while operational, making it a great place to mount solar panels. An alternative placement for the solar panel is on top of the cabin. This however only has a small surface area. The solar panels will charge a battery that will power the DC appliances (e.g. induction plate, lights, etc.) The power output of the solar panels is preferably as high as possible within the dimensions of the TukTuk. The power from a solar panel must be regulated before it can be connected to a battery. To get the best efficiency from the solar panels a charger with an MPPT algorithm is used.

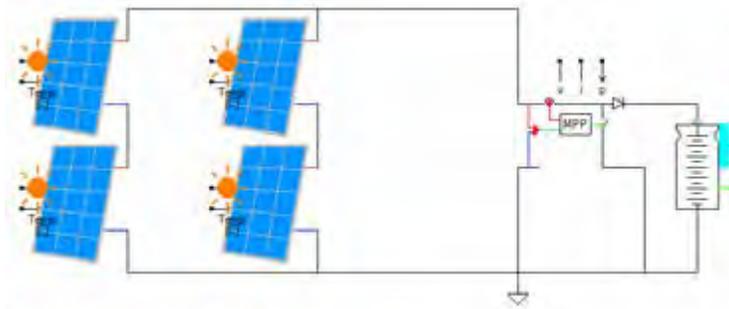


Fig. 5: Simulation of four solar panels with MPPT controller[15].

What is an MPPT algorithm? In layman’s terms, the algorithm is to continuously look at how to get the most amount of power by looking for the highest voltage and highest current combinations possible. There are many algorithms to achieve this[16] but the Perturb and Observe (P&O) are implemented. This MPPT algorithm meets the requirements for a slow and easy-to-implement control to code for an Arduino Nano. The power is measured through the halve bridge and the duty cycle is increased or decreased depending on the amount of power through the halve bridge. Every time the output power increases the duty cycle keeps changing to achieve the maximum amount of power possible. This Maximum Power Point Tracking (MPPT) and the algorithm can be seen in Figure 6. A solar simulator Delta power supply connected to the PC is used to see the live feedback of the algorithm able to reach the MPP.

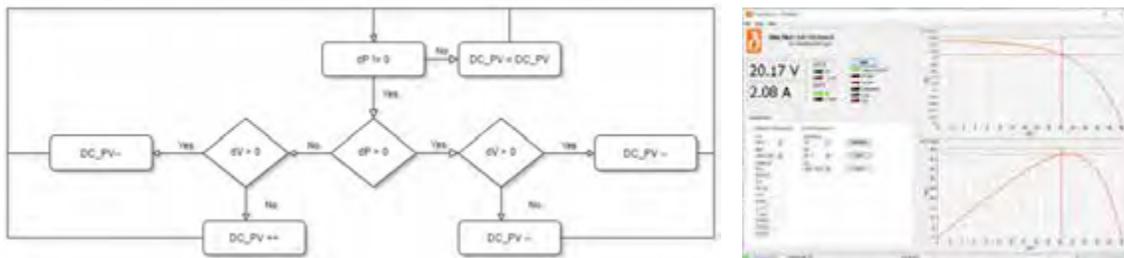


Fig. 6: The MPPT algorithm implemented on a Arduino, PV simulator shows the algorithm reaching the MPP.



Fig. 7 The U4L tested outside compared to a test with a commercially available MPPT.

In Figure 7 we see the MPPT controller works outside in real conditions and has only small deviations from time to time. Compared to a commercially available MPPT controller[17], the self-made version is a bit slower to get to the maximum power point. The deviations are caused by the limited capabilities of the Atmega328p chip on the Arduino. While this proof of concept shows a working principle still the commercially available MPPT is used in the Tuktuk due to the warranty, durability, and robust design to use outdoors.

BATTERIES FOR ENERGY STORAGE

The TukTuk can be showcased everywhere and to be fully off the grid, batteries are needed to store energy. The batteries must be able to power all the devices in the TukTuk and be able to supply power to the high voltage DCDC converter. Batteries come in many different sizes and capabilities, therefore it is important to choose the most suitable for the TukTuk. There are different battery chemistry with their advantages and disadvantages. Currently, the highest density batteries are lithium-based. These are compared to lead-acid-based batteries very light and powerful, but also more expensive and dangerous if handled carelessly. Pricewise and also in combination with the hardware trainer, the lead-acid has the least critical charge algorithm to realize, as there are three states in charging a lead-acid battery. Starting in a constant-current (CC) mode, then constant-voltage (CV) and at last the float charge to compensate for the self-discharge of the battery.

The capacity needed for the Tuktuk is measured on a traditional AC induction hob cooking during a demonstration using power logging tools. During this cooking test, the induction hob is used for almost 5 hours and used 2.64 kWh. This reference is used as a requirement to optimize the simulations models to meet the power consumption of a cooking demonstration.

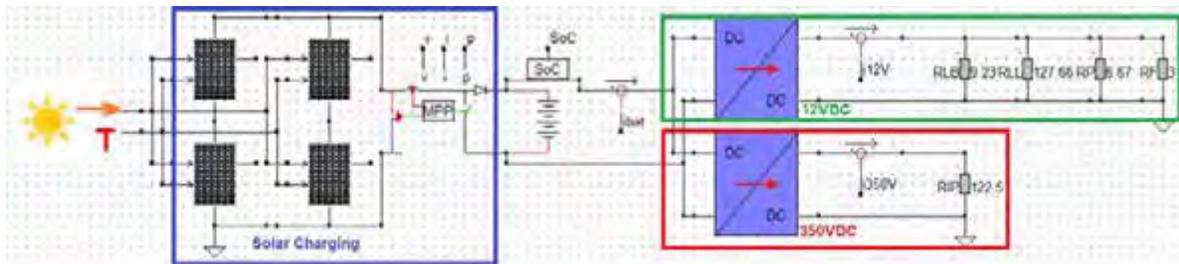


Fig. 8: Solar panels combined with a battery to store the energy. Appliances (resistive) and DCDC converters as loads to draw energy[15].

The lead-acid batteries are put in series to get the desired 48V, the induction hob needs 1,5kW on a voltage of 350Vdc. To reduce high currents from the battery multiple batteries are placed in series. For this configuration four 12V lead-acid batteries are needed. So for how long will this battery configuration power all the devices of the TukTuk? That depends on the capacity of the batteries. To properly size the batteries the power requirement of the system must be assessed. Since the information of the power use is available, but not always constant, estimation must be done. In the simulation in Figure 8, the solar panels of Figure 5 are connected through an MPPT to the lead-acid batteries. In the simulation model, the capacity of the batteries are specified as the configuration needed for the Tuktuk. Also, two DC/DC converters are connected to the batteries to draw energy from the batteries to represent energy drain during use. All the appliances (*induction hob, fridge, lights, etc.*) in the Tuktuk are powered and represented by a resistive load. This is to see how long the batteries will be able to power the appliances while energy is fed into the batteries by the solar panels.

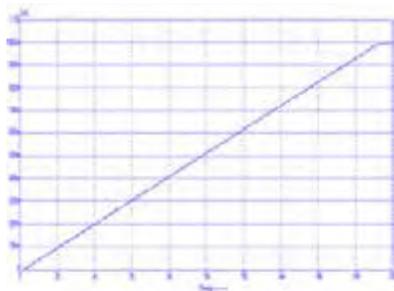


Fig. 9: State of charge during charging

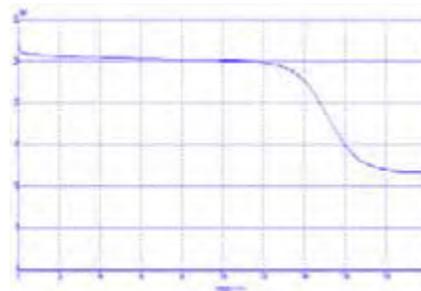


Fig. 10: Discharging the battery with the expected load current

Simulation of charging the battery has been done, the state of charge (SoC) was set to 0% and the components were disconnected from the battery. Figure 9, shows that it takes around 5.5 hours to fully charge the battery. Figure 10, shows the maximum current drawn from the batteries while the resistive loads draw full power from the system. The maximum current drawn from the battery is around 27A while the induction hob draws around 1,5kW from the batteries. These batteries would be able to power the system for at least 3 hours.

To charge these batteries in practice, there are two ways to do this. The first way is by utilizing a charge controller connected to the AC grid to charge the batteries. This can be a great option when the TukTuk needs to be charged fast when there is not enough solar power available. The second, and preferred option, is charging with the MPPT controller of the solar panels. To meet all the safety standards a commercially available inverter is used to charge the batteries, with all algorithms pre-programmed. Also, it has smart functionality to connect to additional modules.

To make sure all appliances have a strong safe connection, a distributor box is utilized, also suitable for high current paths. Also, every appliance has its fuse limited on the expected power that is needed for this appliance. A higher unexpected current will blow the fuse. The distributor box will provide a safe environment when connecting multiple devices with possible bidirectional power flow from unexpected situations. The distributor box is commercially available and also brings information through a Smart Display that is also commercially available. This will show a message on the screen when an error occurs, like a blown fuse, but also battery status, PV power, and load power are displayed.

DCDC CONVERSION

The induction hob uses around 1,5kW and operates at 350V, so the 48V from the battery needs to be boosted with sufficient power. There are different types of DC/DC-boosters, but a Dual Active Boost converter [DAB] is most suited for this application. The topology of the DAB can be seen in Figure 11. The proposed DCDC converter, the DAB, has several advantages, a high power density, it allows bidirectional power flow[19], it is an isolated converter and there are various control methods including implementation of zero-voltage switching. The DAB can also easily be cascading and connected in parallel.

Another advantage is the minimum number of passive components. There are only two capacitors, a high- frequency transformer with an integrated series inductance. This series inductor is the main parameter for the amplitude of the current. Also, soft switching properties can be applied that will allow an increased switching frequency and as a consequence a reduced converter size, especially for the transformer. There is high flexibility when it comes to the optimization of the most important component parameters, being the turns ratio of the transformer, the value of the series inductance and the applied control method. As well as the employed modulation method. Digital control is employed that will allow easy adaption of various modulation methods.

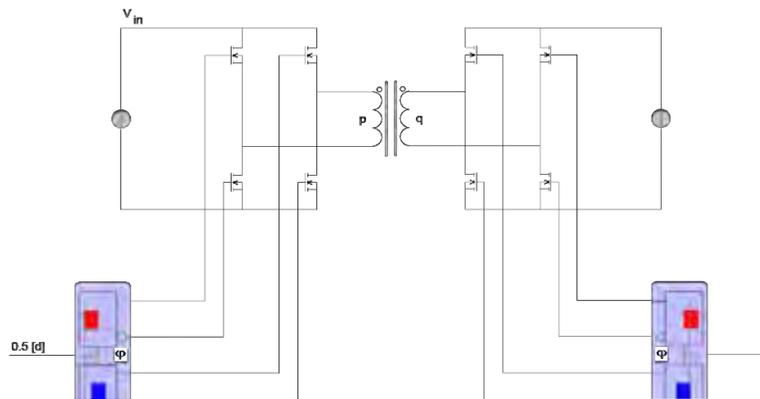


Fig. 11: Topology of an Dual Active Bridge.

Because of these advantages, the DAB is widely used in DC microgrid systems, charging systems for electric vehicles, and energy storage systems and it is therefore applicable for the conversion of the battery voltage of 48 volt to the higher voltage required for the induction hob.

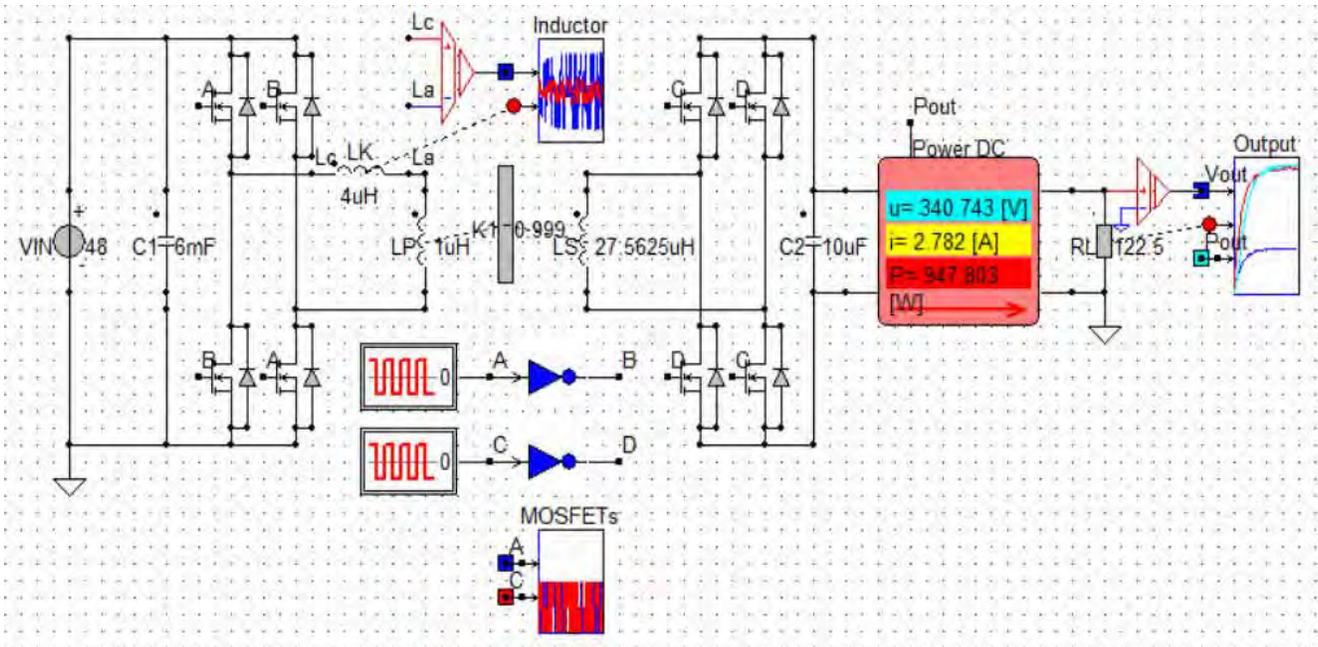


Fig. 12: Simulation of a Dual Active Bridge able to deliver 1kW[14].

A full simulation of the DAB is shown in Figure 12. Here the control algorithm is implemented to transform 48Vdc to 350Vdc. The induction hob is simulated as a resistive load drawing 1kW from the DAB. Finally, the output is measured, to verify if the DAB boost 48V to 350V with 1kW of power drawing from the DCDC converter. The input DC voltage is first inverted to AC by the MOSFET's on the primary side inducing an alternating field in the primary coil. The secondary coil can pick up this energy and depending on the phase shift created by the secondary MOSFET's, the energy transferred can be controlled. The response time of the simulated converter can be seen in Figure 13. It takes up to 5ms to build up energy and bring it over to the output terminal of the DAB with a voltage of 350Vdc.

The practical implementation for inside the Tuktuk, is a DAB evaluation board from Infineon[18]. It is a 3300 W 54 V bi-directional phase-shift full-bridge (PSFB) evaluation board. It is capable of boosting the voltage to 350 V and supplying 1 kW. In practice there is a lack of DC induction hobs (*not commercially available*) and an additional commercially available inverter is placed to be able to connect to the AC grid and also be able to provide AC power to traditional AC induction hobs.

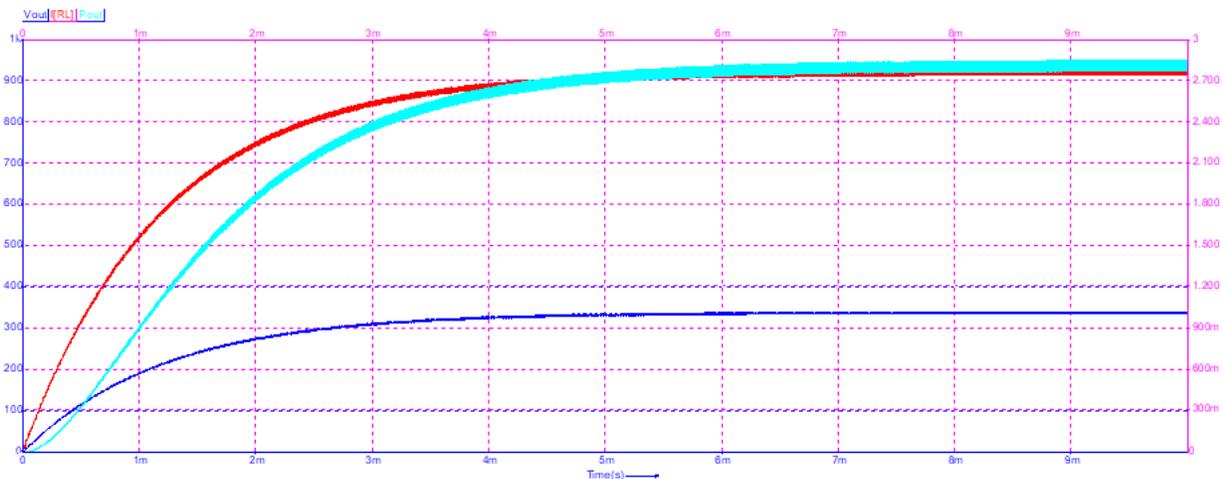


Fig. 13: Simulation graph shows the DAB slowly (5ms) rising to the 350Vdc. Output voltage (blue, left axis), current (red, right axis) and power (cyan, left axis) in Caspoc

DC INDUCTION HOB

An induction hob is based on a resonant converter. A rectified AC voltage is applied to switching semiconductors and depending on the topology used in the induction hob a switching algorithm is chosen. This high-frequency alternating current through the coil of the induction hob induces a secondary current through the bottom of the pan. The bottom of the pan therefore will heat up. The resonant converter operates from a DC bus voltage and is therefore easily applicable to be converted towards a DC grid[20]. As most traditional AC appliances can handle 230Vac, the rectified voltage already reaches a maximum of 326Vdc. Therefore, depending on the appliance, the step to a 350Vdc is possible with minor modifications.

ATAG is one of the first manufacturers who design prototypes of DC kitchen appliances. Also to be able to provide appliances compatible with renewable energy sources. This 350Vdc prototype, as shown in Figure 14, is installed in the Tuktuk and replaces the old gas burners that were installed in this food truck like Tuktuk. In the side panel, the commercially available smart display is mounted to see the energy consumption. The DC Induction hob is one of the first appliances in this DC prototype line, in addition, a DC oven and DC hood fan are built to have a set of appliances that can smartly manage their energy consumption through DC droop control[21].



Fig. 14: DC-Induction hob inside the Tuktuk.

The high power to be able to demonstrate inductive heating is not suitable to test with a low voltage hardware trainer. Therefore, the DC induction hob is simulated using a single-ended resonant converter. As shown in Figure 15, the duration of the gating pulse of the IGBT controls the amount of power that is transferred inside the pan.

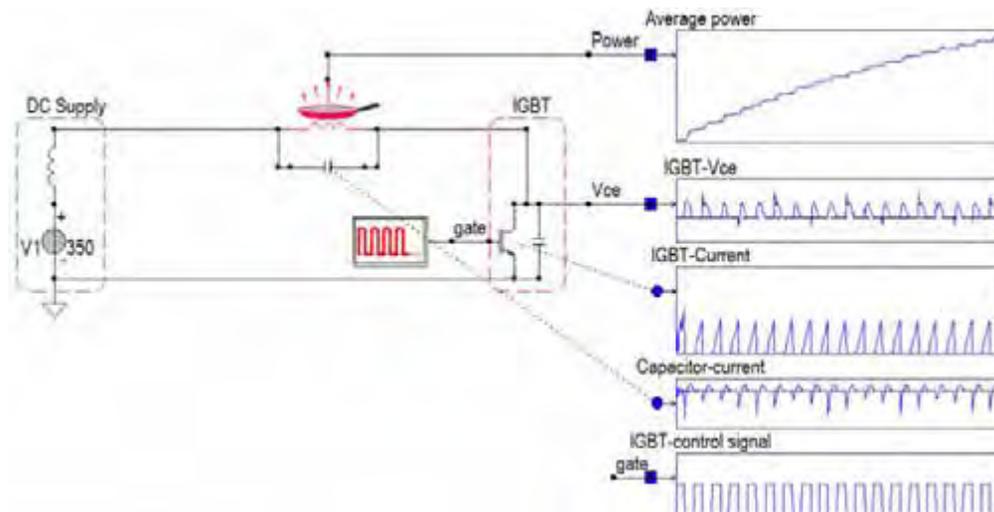


Fig. 15: Inductive cooking using a single-ended resonant converter[20].

PROTECTION

To protect the user against possible dangerous hazards, the first and most simple protection is passive protection. This is inline fuses in-line with all the appliances. And because this system is a floating grid, an Insulation Monitoring Device [IMD] should be added as active protection, it monitors the DC voltage constantly. The IMD is designed to measure the impedance between the line and earth, in this case, the chassis of the Tuktuk. When a low value is measured this may indicate there is a leakage to the protective earth. In this case a DC power relay is switched to entirely turn off the battery. The technique used to detect this kind of earth leakage and the possible switching speed is also simulated in Figure 16. The isoRW425 IMD has kindly been provided by Bender[22] as a commercially available product to use in the Tuktuk. This IMD is a simple and small device, that gives much more safety for use in any kind of environment.

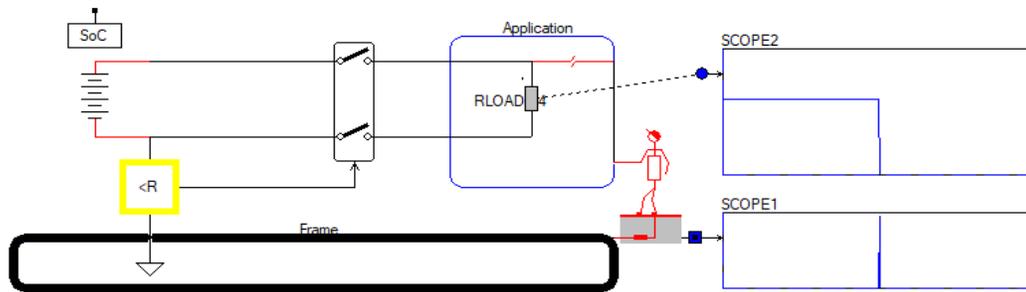


Fig. 16: Simulation of an insulation monitoring device that will switch off when a person leaks current through a ground path[14].

THE ELECTRICAL DRIVE TRAIN

The original Tuktuk is powered by a two-stroke engine for its traction. This is not environment- friendly and not sustainable and renewable. To potentially solve this problem, an electric hub motor is placed as the front wheel, Figure 17 shows the ordered hub motor that has the same size as the front wheel of the Tuktuk. The hub motor is of the type: brushless direct current motor. This type of motor is very common among electrical vehicles. The power for the wheel can come from the 48V battery pack of the Tuktuk and the only thing to drive the wheel is a high-end microcontroller. The specifications of the hub motor are 48Vdc and 2kW. The specifications of the hub motor are very important while choosing a motor driver. The MOSFET's in these controllers must be able to handle the peak current when accelerating from a standstill. Also, the microcontroller, should be able to drive the MOSFET's.

To find out how fast the TukTuk will be able to drive with this specific hub motor, the Tuktuk is simulated as a moving vehicle, as shown in Figure 18. According to the simulation, the TukTuk should be able to reach a maximum speed of 20km/u within 90 seconds under perfect circumstances (*flat road, no wind*). This should be enough for demonstration purposes but will not have enough power to drive on a normal road.



Fig. 17: The used 2kW hub motor.

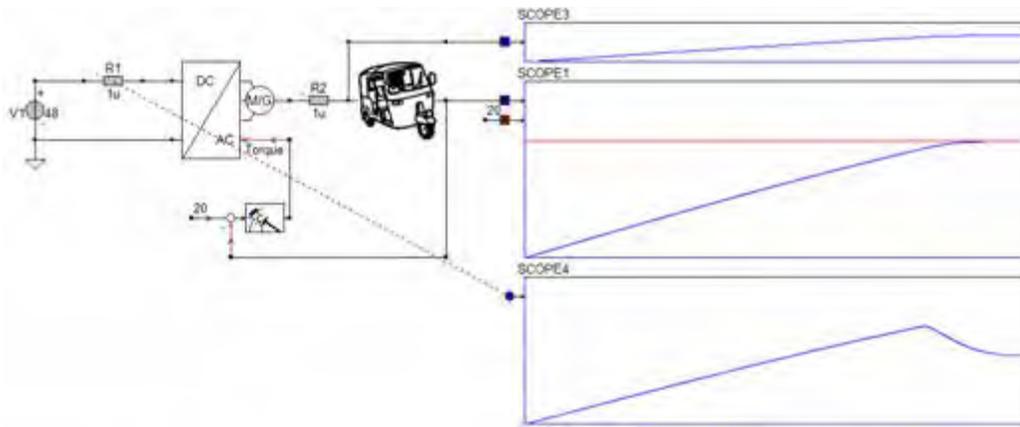


Fig. 18: Simulation of the 2kW hub motor inside a Tuktuk like a vehicle, weight matches the Tuktuk[14].

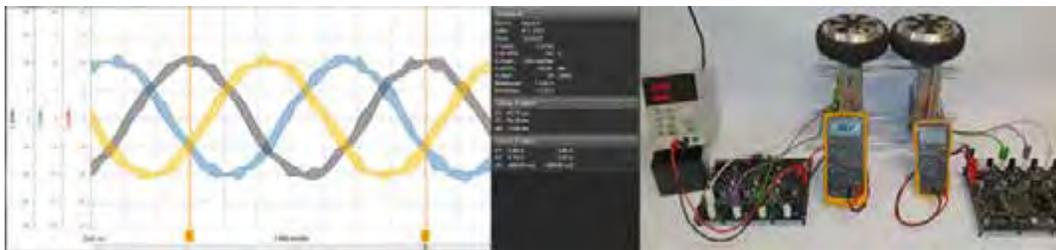


Fig. 19: The measured three-phase output and the practical test setup realized with two U4L boards to drive two motors.

The motor control was first tested with the help of an external motor drive train set up, see figure 19. In this setup two, equally sized motors are mechanically coupled, where one machine acts as a motor while the other machine acts as a generator. The U4L is used to control both machines, where one machine is speed controlled and the generator is simulating the mechanical load and therefore configured as torque controlled. Although the wheel hub motor includes Hall sensors for rotor position detection, a sensorless Field Oriented Control method is applied. The advantage is that only three wires are required to power the motor and the vulnerable sensor wires are not required, reducing the failure rate of the drive train. The inverter is powered from the 48 volt batteries directly and cascaded speed-current control is implemented as a digital control in the C2000 [23].

A first experiment to test the wheel hub motor is shown in fig. 20. The hub motor was mounted underneath the Tuktuk for testing purposes. In this way, the test could be performed in an early stage before the actual replacement of the front wheel by the wheel hub motor. With a small moment of inertia, the used hub motor can get the Tuktuk moving. Therefore this proof of concept is working as expected. A higher power hub motor should be chosen to use the Tuktuk to drive a longer distance. All the components used inside this Tuktuk make it weigh around 500kg, also in simulations, a normal Tuktuk would have a better performance with a 2kW hub motor.



Fig. 20: The hub motor mounted for testing performance under load.

With this last component ready to install in the Tuktuk, the whole Tuktuk is 3D-modeled. In this way, all dimensions are clear and give the possibility to fit all the commercially available components. These components already are available to download and give a good indication of the possibility of placing all of these components. While the hub motor is in front of the chassis the highest weight is on the middle of the back suspension. This was the only possible location to place the batteries and stay balanced as much as possible.



Fig. 21: The 3D modeled Tuktuk with used electronics modeled.

IMPLEMENTATION AND DEMONSTRATION

With all components and converters, 3D modeled the full DC nano grid installation can be implemented in the Tuktuk. The old installation of the Tuktuk contained a gas installation for gas burners, as this Tuktuk is used as a festival food truck. These old gas burners were replaced with DC and AC induction hobs (*to have both options available*). And the gas tank, in Figure 22, is removed. This backplate is then replaced with the DC nano grid and appliances, as described in the previous sections. Figure 23, shows the new installation.



Figure 22: Old gas installation



Figure 23: New DC installation in theTuktuk

After the TukTuk was installed, tests have been carried out to compare the simulations to the real-life results. To make sure the system doesn't run too hot, a thermal imaging camera is used to check the temperatures of the system, cables, and connectors in particular. Wrong installed connections will have a high impedance and therefore will get hot through the high current flowing, Figure 24,25,26.



Figure 24: Shunt

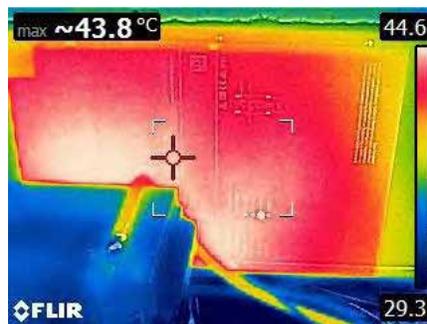


Figure 25: Inverter



Figure 26: Wires

To test the system the induction hob was used to draw high current through the system. The information of the power draw was provided by the built-in screen of the Tuktuk. A pan of water was used to have a real load on the induction hob. The first test was a 50% power setting on the induction hob. Figure 27 shows the SoC if 1kW is drawn from the system until the batteries are empty, this gave a runtime of around 2 hours. The total runtime of the system was around 45 minutes with a 2kW cooking test, the SoC can be seen in Figure 28. Drawing higher currents from the battery decreases the running time dramatically. The dynamic test, in Figure 29, consists of a real BBQ cooking session with variable power drawn. Since it is not predictable how a chef will use the induction hob, the results will be truly dynamic. The results were better than expected comparing the results to the 1 and 2kW tests.

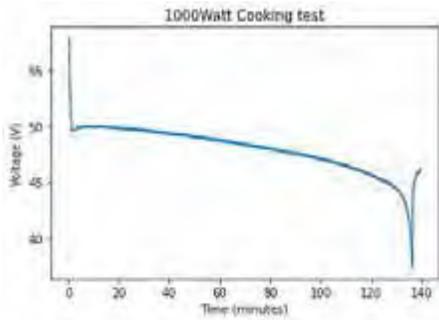


Figure 27: Cooking test 1kW

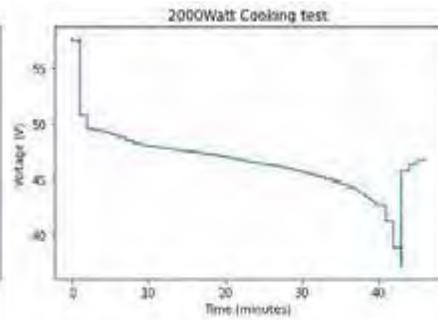


Figure 28 Cooking test 2kW

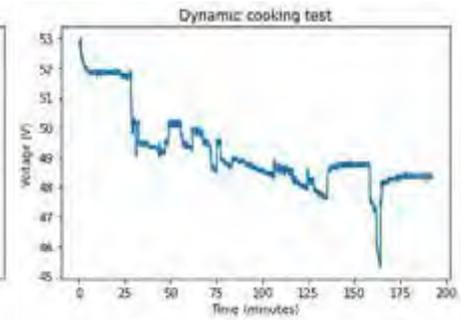


Figure 29: Dynamic cooking test



Figure 30: The Dynamic BBQ cooking session to test the whole Tuktuk system in practice.

The dynamic BBQ test can be seen in Figure 30, with an active power logger connected, supported by Fluke. When the batteries are fully drained by the use of the Tuktuk, they can be charged with the help of the inverter. It is very important to know when the batteries are fully charged from fully discharged. Therefore a charge test is also carried out to find out how long it takes to charge the batteries. The plot of the SoC while charging can be seen in Figure 31. Using the Tuktuk dynamically gives more cooking time than synthetic test at fixed power. A measurement of the voltage level during a live demonstration of the food truck reveals a 5% voltage drop over 180 minutes of using the inductive cooking hub.

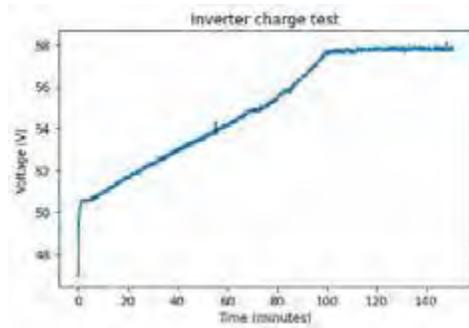


Figure 31: SoC while charging the batteries.

CONCLUSION

In this paper, a newly introduced food truck built inside a Tuk-Tuk is discussed. The complete drive train including the dc grid that is required to control the food truck is designed and implemented in a gasoline-powered food truck, where the gasoline drive train and gas tanks for cooking are removed. The four 12 volt lead-acid batteries in the dc grid supply an inductive cooking hub and the refrigerator, as well as supplying power for the electric drive train. Solar panels on the roof and side of the food truck charge the batteries. An isolation detection is added to ensure safe operation and can detect any short circuit to the chassis of the food truck.

This demonstrator aims to show the minimum requirements for implementing a dc grid to create a self-supplying microgrid. The main battery voltage level is selected as 48volt, from which a lower 12 volt for the auxiliary supplies and a 350 V DC for the induction cooking hub are created. Since the food truck is a mobile vehicle, the type of electric grid is an isolated system, however, the vehicle and the metal frame inside the vehicle are considered as the grounding for the electric system.

The results from the performed simulations to study the overall system behavior, as well as the detailed operation of the various components, agree with the measurement results. Simulations and measurements were performed for the solar maximum power tracker, the working of the DCDC converters, and the simulation of the drive train of the electrified Tuk-Tuk.

The measurements show that using these fully charged batteries, the induction hob, refrigerator, and lighting can operate for at least 45 minutes when using continuously 2kW of power and over 2 hours when using continuously 1kW. The difference originates from the higher overall losses when withdrawing a higher amount of power from the batteries. The demonstration of a dynamic cooking test, being a kind of cooking drive cycle, revealed 180 minutes of using the induction hob is possible. A measurement of the voltage level during a live demonstration of the food truck reveals a 5% voltage drop over 180 minutes of using the inductive cooking hub.

ANOWLEDGMENT

The authors thank ATAG for their cooperation and the generous support of the equipment and the food-truck Tuktuk. The authors are grateful for the support of Bender and Fluke for additional devices to conduct this research. Also, all students who participated in the DC-LAB projects provided by The Hague University of Applied Sciences and research group Energy in Transition.

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RETROFITTING AC CABLES TO DC FOR PUBLIC LIGHTING, REFLECTIONS AND TRANSIENTS DURING SWITCHING

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ABSTRACT

The CombiCable is a power distribution cable that consists of four main conductors used for transportation of the three-phase AC power to the consumers. In the same cable, there are four auxiliary conductors situated around the main conductors and these are used for powering public lighting, traditionally with AC power. Recently, public lighting has shifted towards LED lighting, requiring DC power instead of AC. The question is if the four auxiliary conductors can be used for DC powering the public LED lighting, instead of adding a new underground cable for public LED lighting. Retrofitting the auxiliary conductors in the existing CombiCable means a considerable saving in material and labor costs, as there would be no need for replacement of the cable for applying DC-powered public LED lighting. Since the CombiCable has been widely applied in the Netherlands with over 40.000 kilometers of cabling, reusing these cables would save a lot of material and labor costs.

Some experimental research has been carried out to investigate whether it is possible to apply the combination of AC main power and DC power for the public lighting in the same CombiCable. Before implementation, the cross-coupling and electromagnetic interference between the AC and DC system have to be investigated to ensure the reliability of the system. In particular the impact of transient voltages and currents in the AC section of the cable as a result of switching actions in the DC section of the cable.

To investigate this problem, a simulation model of the CombiCable is a valuable tool. In this paper, a setup of a simulation model for the CombiCable will be described that makes it possible to investigate and observe the transient voltages in the cable during switching actions. The simulation results give insight into the behavior of the CombiCable when applying AC and DC simultaneously in the same cable.

KEYWORDS

Energy distribution, CombiCable, AC power, DC power

INTRODUCTION

Electrical power distribution in distribution grids is mainly being performed by the application of the CombiCable. Such a cable consists of four main conductors and four auxiliary conductors. The CombiCable construction is shown in Figure 1a and the conductor positions are shown in the cross-section of the cable in Figure 1b. It is shown that the cable is constructed by its conductors that are insulated by several insulation layers. It is further shown that the thickness of the four auxiliary conductors is relatively small and that these conductors are located on the outer side in between the main conductors.



Figure 1a. CombiCable construction [1]

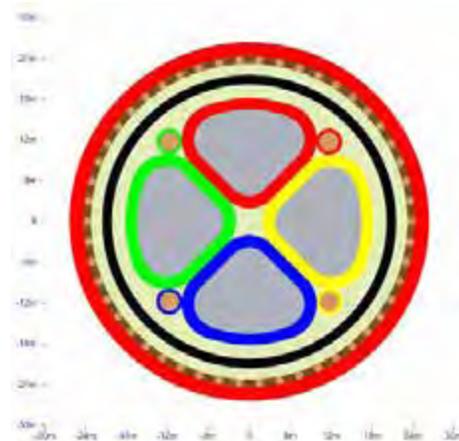


Figure 1b. Main and auxiliary conductor locations

In the normal steady-state operation of the distribution power grid, the main conductors of the cable carry the AC power current for distributing the AC power to the consumers. Simultaneously, the auxiliary conductors have been used for powering public lighting, for which also AC power is required. Nowadays, LED lighting is coming up more and more and these lights require DC power instead of AC. Investigating the feasibility to combine AC and DC power on the same cable is of large importance from several points of view. In the case of switching actions on the AC cable side during steady-state operation of the power grid, voltages are induced in the neighboring conductors since a change in magnetic field strength will result in an induced voltage. These induced voltages will propagate along the cable conductors. The severity of these induced voltages depends on the electrical and magnetic properties of the cable materials that influence the coupling between the adjacent conductors. As a result of the coupling between conductors, induced voltages can cause reflections occurring at cable junction points. Junction points are locations where there is a change in impedance resulting in a discontinuity of the voltage and current propagation. At a junction point, a part of the voltage will be reflected and the other part will be refracted. Reflected voltages could result in large voltage peaks in the cable. Some earlier research has been done on the applicability of the CombiCable [1], [2], [3]. Also, experimental modeling work has been done [4].

In this work, the research on the cable is described to answer the question of whether it is possible to apply AC power and DC power simultaneously in the same cable when switching actions occurred. In previous experimental work [1], measurements have been performed on a CombiCable test setup to investigate the coupling between the main conductors and the auxiliary conductors. Based on these measurements, the coupling parameters are estimated and validated by a simulation model. In this paper, a simulation model for the CombiCable is presented to investigate the severity of switching effects on the cable. In [5] an overview is given of auxiliary loads on a public lighting network. The monitoring and control of public lighting is discussed in [6]. Many LED drivers that are suitable for connection to an AC grid can also be connected to a DC grid. The driver presented in [7] has no transformer at the input terminals and can therefore be directly connected to a DC grid. Droop control in case of a DC microgrid controlled public lighting is explained in [8]. In [9] the use of the DC traction supply for use in public lighting via a three phase AC grid tied inverter is discussed. The use of DC microgrids is described in [10][11] and protection of DC grids in [12]. In [1] the application of the auxiliary conductors in a AC grid for a DDC micro grid are discussed. What is the reason to replace AC with DC for street lighting? The main advantage is that there is no voltage drop due to the inductance of the cable and therefore more street lights can be connected to a longer cable. In this way, costs are reduced as less power supply feeders are required per kilometer. Secondly, the earth leakage detection is possible over a longer cable because there is no leakage current due to the capacitance of the cable. Therefore any leakage current at the end of the cable can be detected at the power supply.

In section II we cover the basics of the CombiCable and how is applied for street lighting. Here we discuss the application of AC or DC and what the advantages of a DC grid for street lighting are. Also, the CombiCable is introduced and its parameters, and especially the cross-coupling, are discussed and presented. The mathematical model for a power cable is discussed in section III and the electrical wave propagation and reflection are outlined in section IV for a general power cable. In section V the simulation results for a cable subdivided into several segments are presented. The cross-coupling in the CombiCable when combined AC and DC distribution is done using the same CombiCable is discussed in section VI. The model showing the influences of cross-coupling are presented in section VII. Section VIII shows the final circuit model for the CombiCable that is used to show the cross-coupling between the AC and DC grid in the CombiCable. In section IX two simulations of a 4km and a 3km DC grid with 40 and with 60 street lights is presented.

COMBICABLE

Traditionally the CombiCable is used to supply both households with AC via the main cores. Using a switch, the street lights connected to the auxiliary cores can be supplied from the same AC distribution system, as is shown in Figure 2.

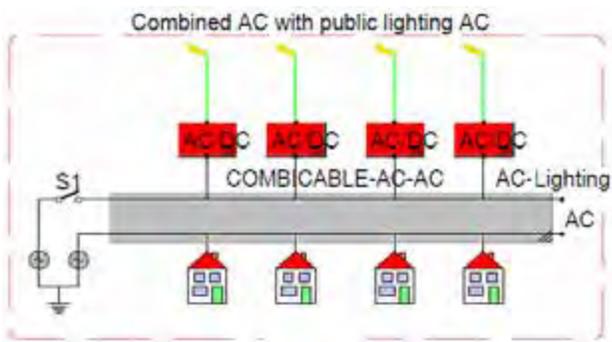


Figure 2. Distribution system using AC[13]

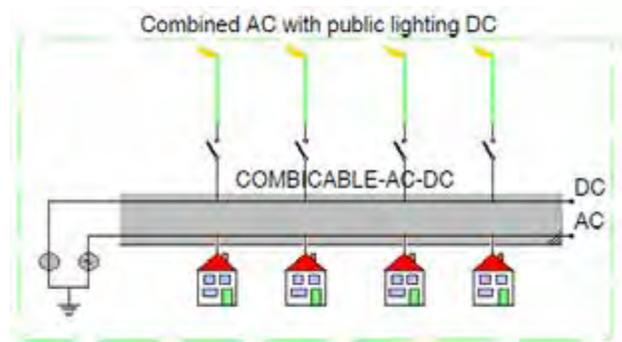


Figure 3. Distribution system using AC and DC[13]

Retrofitting the CombiCable means that the auxiliary cores are now used to distribute a DC grid for feeding the street lights, as is shown in Figure 3. Each street light has a remotely controlled switch, as the DC grid remains constantly supplied over the auxiliary cores. The reason for this is that the DC grid can also be used for feeding other applications such as telecom and surveillance.

CABLE TRANSMISSION LINE MODEL

Switching actions in cables might result in high-frequency voltages and current waves propagating along the cable and causing reflections to occur. To investigate the behavior of propagating voltage and current transients and the influence of reflections, an accurate model of the CombiCable is needed. Several cable models are available with each their limitations concerning accuracy. For investigating switching effects, a transmission line model is needed as shown in Figure 4 [14]. This figure shows a cable segment having a certain physical length indicated by dx , consisting of infinite small segments within each segment the cable's electrical and magnetic properties are taken into account. A total physical cable section with a certain length can be modeled by an infinite amount of these cable segments. The transmission line model is shown for a two-conductor cable segment. The transmission line cable model is a sufficient base model for modeling the CombiCable that provides sufficient accuracy for investigating switching effects and studying the voltage and current reflections along the cable.

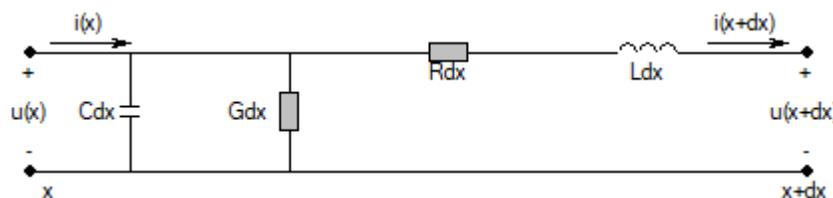


Figure 4. General transmission line model [14]

When considering the model shown in Figure 4, we can find the expressions for the series impedance and the shunt admittance. The series impedance is formed by the resistance r and the self-inductance l is can be written as[14]:

$$z = r + j\omega l \quad (1)$$

The shunt admittance is formed by the conductance g and the capacitance c and can be written by:

$$y = g + j\omega c \quad (2)$$

In Figure 4 and equations (1) and (2):

r is the resistance per unit length [Ω/m]

l is the self-inductance per unit length [H/m]

g is the conductance between two conductors per unit length [S/m]

c is the capacitance between two conductors per unit length [F/m]

z is the series impedance [Ω/m]

y is the shunt admittance [S/m]

When taking Figure 4 as a starting point, we need to perform some mathematical analysis to arrive at a set of applicable equations. Applying Kirchhoff voltage and current law to the circuit in Figure 4, we can describe the voltage difference over the series impedance and the current difference between the locations x and $x+dx$ by taking (2) into account, we arrive at the Telegrapher's equations [14]:

$$dV = Izdx \quad (3)$$

$$dI = (V + dV)ydx \quad (4)$$

These expressions can also be written in the form of two linear first-order differential equations:

$$\frac{dV}{dx} = zI \quad (5)$$

$$\frac{dI}{dx} = yV \quad (6)$$

Taking the derivative within respect to x of (5) and (6), the following second-order differential equations are obtained:

$$\frac{d^2V}{dx^2} = z \frac{dI}{dx} \quad (7)$$

$$\frac{d^2I}{dx^2} = y \frac{dV}{dx} \quad (8)$$

When these equations are combined, meaning that when (6) will be substituted into (7) and (5) will be substituted into (8), we arrive at a set of second-order linear differential equations:

$$\frac{d^2V}{dx^2} = zyV = \gamma^2V \quad (9)$$

$$\frac{d^2I}{dx^2} = yzI = \gamma^2I \quad (10)$$

In (9) and (10), γ is the so-called propagation constant of the transmission line and it determines the voltage and current wave propagation properties when the wave is traveling along the cable. In general, the propagation constant γ takes into account the attenuation of the wave and its phase shift. According to (11). The so-called characteristic impedance of the line Z_0 depend on z and y according to (12):

$$\gamma = \sqrt{zy} \tag{11}$$

$$Z_0 = \sqrt{\frac{z}{y}} \tag{12}$$

Based on these two differential equations and applying the boundary condition for both the voltage and current values at the receiving end of the transmission line section, V_r and I_r , two general solutions can be found for describing the voltage and current values at any location x along the transmission line. Finally, the voltages and currents at any location x can be described by two hyperbolic equations, according to (13) and (14) [14]:

$$V(x) = V_r \cosh(\gamma x) + Z_0 I_r \sinh(\gamma x) \tag{13}$$

$$I(x) = I_r \cosh(\gamma x) + \frac{V_r}{Z_0} \sinh(\gamma x) \tag{14}$$

ELECTRICAL WAVE PROPAGATION AND REFLECTION

The transient voltages and currents will propagate as electromagnetic waves along the cable according to (13) and (14). The propagation properties depend on the cable’s electrical and magnetic parameters and are described by the propagation constant γ . The traveling wave propagation velocity v can be described in terms of the permittivity and the magnetic permeability of the cable material, described by the equation:

$$v = \frac{1}{\sqrt{\epsilon_0 \epsilon_r \mu_0 \mu_r}} \tag{15}$$

In (15):

- ϵ_0 is the permittivity of vacuum [F/m]
- ϵ_r is the relative permittivity of the cable insulation material
- μ_0 is the permeability of vacuum [H/m]
- μ_r is the relative permeability of the cable material

Having the expressions for the general voltage and current for a propagating wave along a transmission line, we can observe the reflections that occur at a junction point along the line when switching actions occur. When a traveling voltage wave arrives at a junction point, that’s a point where the wave experience a change in impedance, reflection occur and this means that an incident wave and a reflected wave must be distinguished. The resulting voltage at the junction point is equal to the sum of the incident wave and the reflected wave and thus the resulting voltage depends directly on the amount of reflection and thus on the difference in impedances.

The reflection coefficient for a wave propagating through the cable towards the load can be expressed in terms of the impedances, according to (16):

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{16}$$

In (16):

Z_L is the impedance of the load [Ω]

Z_0 is the cable characteristic impedance [Ω]

The meaning of the load and the cable impedance can be made clear by considering a simple practical simulation circuit. This test circuit that consists of a voltage source, a switch, a transmission line, and a load impedance is built up to show the effect of voltage reflections that occur along the transmission line. In Figure 5, this test circuit is shown.

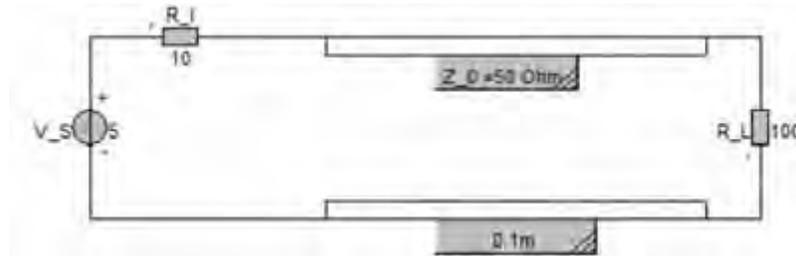


Figure 5. Simulation test circuit for reflection measurement

In Figure 5, the voltage source impedance is 10 Ω and the voltage is equal to 5 V, the cable impedance is equal to 50 Ω and the load impedance is 100 Ω . The voltage source at the sending end of the cable has an impedance of 10 Ω . The voltage source in Figure 5 was switched on at time instant $t = 0s$. The propagation time between the sending and the receiving end of the test circuit is about 1 ns, meaning that this is a short cable section. Directly after switching on the voltage source, voltage division takes place because the 10 Ω resistance of the source is in series with the 50 Ω cable impedance. This results in a voltage level of about 4,17 V (17) to travel along the cable section towards the load impedance.

$$V = 5 V \cdot \frac{50 \Omega}{50 \Omega + 10 \Omega} = 4.17 V \quad (17)$$

At time instant $t = 1 ns$, the voltage arrives at the load impedance at the receiving cable end, equation (16) is applied and the reflection coefficient at the load impedance is equal to 1/3. This results in a reflected voltage level of:

$$V = 4.17 V \cdot \frac{1}{3} = 1.39 V \quad (18)$$

The resulting voltage level at the load impedance at time instant $t = 1 ns$ is equal to the sum of the incident wave and the reflected wave and in this case, this is equal to 5,56 V. After this first reflection instant, the reflected voltage wave travels back to the sending end, meaning that at the voltage source the reflection coefficient is equal to -2/3 as at this location there is a junction point as well. At time instant $t = 2 ns$, the reflected voltage arrives at the sending end and the reflected voltage is about -0,93 V. At time instant $t = 3 ns$, the voltage at the load side is equal to 4,32 V. The procedure will repeat until the final steady-state voltage value is reached.

From (16), it can be seen that if the load impedance is large compared to the cable impedance, the reflection coefficient is approximately equal to “1”, meaning that the reflected voltage has the same value as the incident voltage. The result is a doubling of the voltage peak at the load impedance. In the situation that there is a short cable section terminated with a high load impedance, many voltage reflections occur in a short period as the propagation time of a short cable is relatively small and thus the attenuation is also small. High voltage peaks can be built up in this way and this may stress the cable insulation material.

COMBICABLE MODEL AND SWITCHINGS

The transmission line model explained in the previous section is the most accurate model for investigating voltage and current reflections resulting from switching actions. However, some simplification to this model can be made without losing much accuracy. A simplified cable model can be made by dividing the cable length into lumped sections, so-called PI sections. Each section represents a piece of the total cable length and has lumped circuit parameters. This is done for the CombiCable model.

The parameters are [2]:

$$R = 2973 \text{ m}\Omega/\text{km}$$

$$L = 1417 \text{ }\mu\text{H}/\text{km}$$

$$C_{ac} \text{ (capacitance aux-core)} = 66 \text{ nF}/\text{km}$$

$$C_{as} \text{ (capacitance aux-sheath)} = 78 \text{ nF}/\text{km}$$

The accuracy of the PI-section models depends on the number of sections that are used for a certain cable length. The accuracy of the model is investigated by simulation of a switching action on the cable. In this simulation, the cable has a length of 100 meters and at the sending end, a DC power voltage of 350 V is applied. The voltage responses are shown for two pieces of sections for 100 m. CombiCable. In Figure 6, the voltage responses at the cable receiving end are shown. The red line shows the response when 1 section is used. The green line shows the transient response voltage when 50 sections are used. The auxiliary cable is switched on the DC power voltage of 350 V at time instant $t = 0$ while the cable receiving end is terminated with a 150 W load. In Figure 6, the voltage responses at the cable receiving end are shown. From these plots, it can be seen that the voltage peak is about 825 V and after about 40 ms the voltage oscillation is damped out.

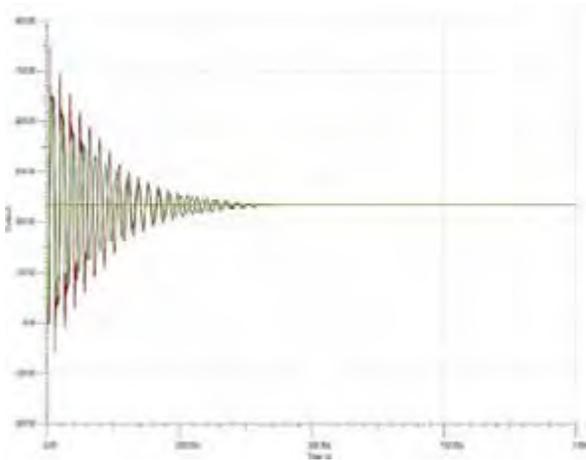


Figure 6. Switching transient voltage

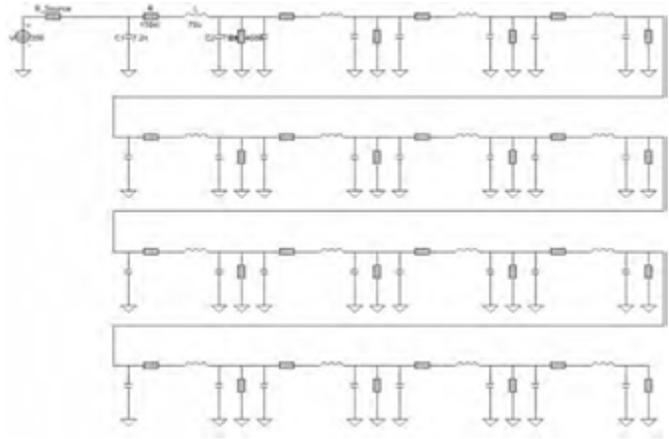


Figure 7. CombiCable model represented by 16 PI sections

In Figure 7, the final model is shown representing the CombiCable with a length of 100 meters. This model is used to perform further switching tests to measure the voltage response and it consists of 16 PI-sections.

CROSS COUPLING

In the previous sections, the reflection and transmission in a general single conductor cable model were elaborated. The CombiCable consists of 4 main conductors and 4 auxiliary conductors within the same shield. The PI-section cable model from Figure 7 considers the inductance of a single conductor. In reality, most AC cables contain more conductors and there is inductive and capacitive coupling between the conductors. The parameters used for the PI-section cable model from Figure 7 are such that they can be considered as equivalent for a multiconductor cable and they include the effect of the inductive and capacitive coupling between the conductors and the shield. These are the parameters that are measured by the manufacturer and given in the datasheet. In the CombiCable also the coupling between the conductors is present, but secondly, there is also coupling between the main and auxiliary conductors. It are these couplings that are of interest when investigating whether the CombiCable can be used for combined AC and DC power transfer. In the following sections, we will elaborate on the coupling between the conductors and how this is incorporated in the model. Secondly, simulations will visualize the effect of this coupling between the main conductors in use for AC and the auxiliary conductors in use for DC power transport.

CROSS COUPLING MODEL

The CombiCable is modeled by an equivalent circuit model, that includes all couplings between all conductors and the shield. The influence of cross-coupling can be studied independently from reflections, given the fact that the eigenfrequencies of the reflections are a multiple of the low-frequency effects due to the cross-coupling.

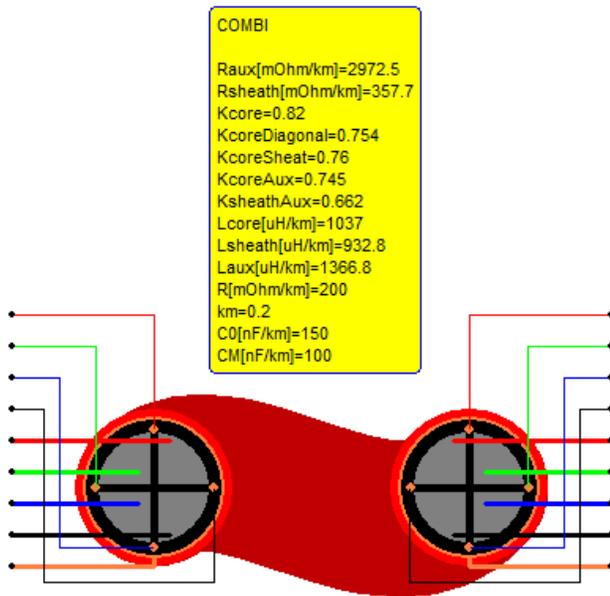


Figure 8. Final circuit model



Figure 9. Online CASPOC cable calculator [13]

For example, Figure 6 shows an eigenfrequency for reflection of roughly 50kHz. The effects of cross-coupling are mainly related to switching actions on the DC lines and the magnetic field from the AC 50Hz current. Fast transient response is expected when turning on a load on the AC as well as on the DC side. Any reflections because of this switching can be calculated using a single PI section, however, multiple PI sections will increase the accuracy. To keep the final circuit model limited in size, only a single PI section is included in the CombiCable model. If multiple PI sections are required, multiple models can be placed in series, where the length for each model equals the total cable length divided by the number of sections. More important inside the CombiCable circuit model are the inductive and capacitive couplings between each conductor and the shield. Therefore the model includes both four main conductors, four auxiliary conductors, and the shield. Each conductor is modeled by an inductance and all conductors are coupled to each other by their mutual inductance. Secondly, the capacitance between all conductors and between the conductors and the shield is modeled. The parameters for the inductive coupling are based on the geometry of the cross-section of the cable. It is assumed that the length of the cable is of a multitude larger than the diameter of the cable. In that case, from the two-dimensional geometry, the mutual inductance and capacitive coupling can be calculated. The resulting parameters are the inductance per conductor as well as the mutual inductance between all conductors. In that way, the inductive cross-coupling between conductors finally defines the total inductance of the CombiCable. The capacitance is defined between all conductors that face each other, as well as the capacitance between the conductors and the shield. The final circuit model is shown in Figure 8. The electrical connections are both on the left and right sides of the cable for each conductor. The parameters for the model are shown in the yellow box in this figure. The Caspoc design tool[12], in Figure 9, is used to calculate the parameters for this typical cross-section of the CombiCable.

CIRCUIT MODEL

The CombiCable model is used in simulations to investigate the cross-coupling between the AC and DC distribution grid. The cross-coupling is studied by using the complete circuit model, where each core is modeled by its equivalent inductive and capacitive model. The mutual inductive coupling and the capacitance between each core are included in this model and thus the simulations can reveal how much disturbance the AC grid is induced on the DC grid and vice versa.

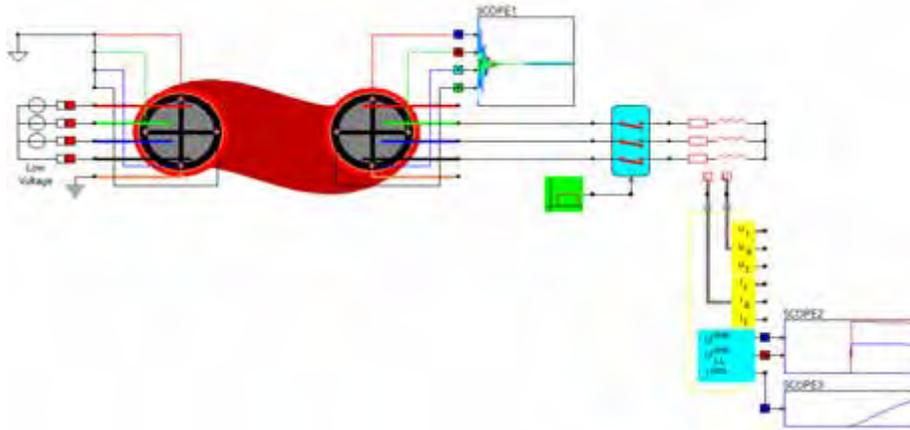


Figure 10. Simulation of disturbance in a DC grid due to switching in the AC grid.

In Figure 10, the simulation shows the disturbance in the DC grid due to a switching action on the AC grid. The load in the AC grid increases suddenly and this is causing a transient on the DC grid. The DC grid is not supplied in this simulation, so at the end of the cable, we can measure the induced voltage.

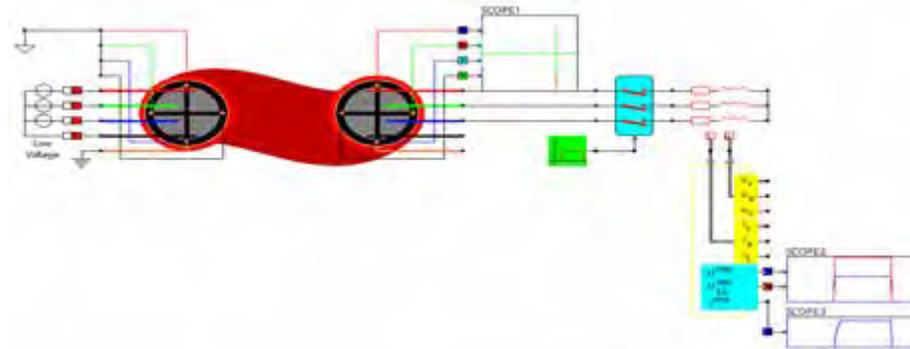


Figure 11. A load on the AC grid is connected. Scope 1 shows a voltage spike occurring in the DC grid while disconnecting the AC load on Scope 2 and 3.

In Figure 11, a load on the AC grid is connected during an interval of 70ms. Especially the turn-off of this AC load is visible in the DC grid, where it generates a large induced voltage spike. The disturbance of switching a DC load in the DC grid on the AC grid is shown in Figure 12, where during several periods of the AC grid a load is connected to the DC grid. Because of the cross-coupling, the DC currents induce an unbalance in the electromagnetic field inside the CombiCable, giving rise to a current in the neutral core for the AC grid. A small 50Hz ripple can be observed in the overall AC grid on the neutral core and this influences the line and phase voltages in the AC grid.

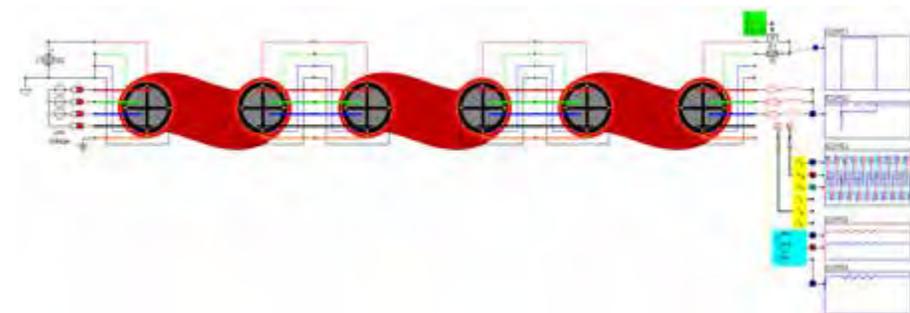


Figure 12. A small 50Hz ripple can be observed, on scope 2, on the neutral core of the AC grid.

DC GRID MODEL

In Figure 13, a DC bipolar grid of 3km feeding 60 street lights at a distance of 50 meters. Use is made of a bipolar grid of plus 350 V, 0 V, and minus 350 V. This means that three cores are required, where the current is distributed by the plus and minus core, while the neutral core carries no current. The initial current during powering the grid is shown in the upper scope where the initial current is compared to an initial current of a single component model. Visible is the transient from the DC grid model with pi sections, compared to the first-order response from the single component model. The voltage after 3km of the grid is reduced to 312 volts, yet enough to feed the street lights at the end of the cable.

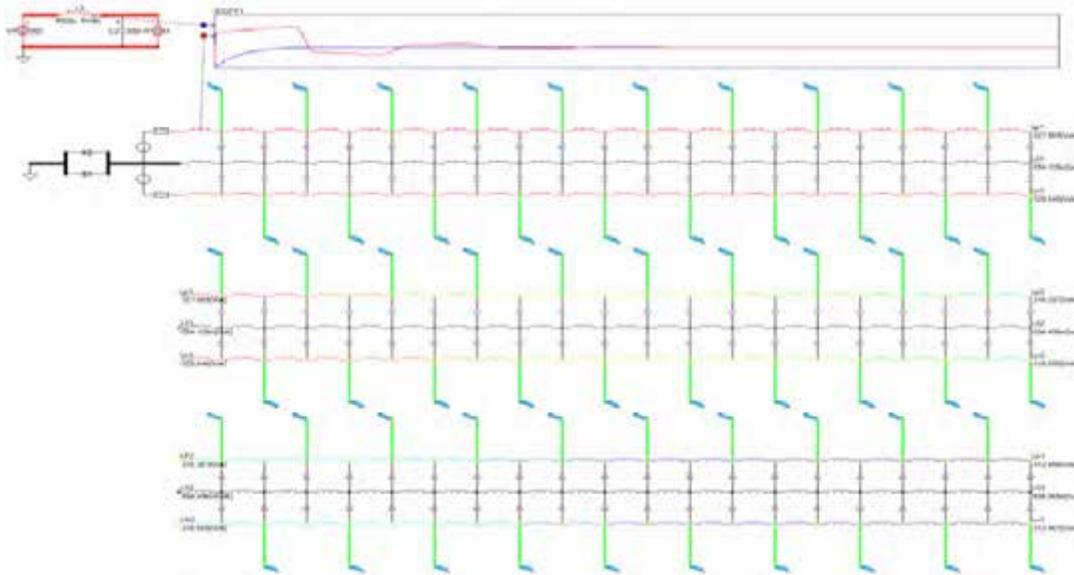


Figure 13. DC bipolar grid of 3km feeding 60 street lights at a distance of 50 meters.

In Figure 14, a DC grid is modeled with 40 street lights each at 100 meters distance over a total length of 4km. A cable with dual cores (*plus, minus*) of 4mm² is used to power the street lights. On both sides of the DC grid, a power supply is connected feeding the street lights from both sides. The power supply at one side of the grid is having a nominal voltage of 350 volt. The other supply has a nominal voltage of 380 volt. In this way, the power supply with a higher nominal voltage will supply more power (around 2.2kW) to the grid than the one with lower nominal voltage, which supplies only 1.5kW. The importance of the simulation is that it illustrates how the feeding of the DC grid can be done from two sides independently and the amount of power to be delivered can be controlled by controlling the DC voltage. This so-called droop control is utilized in DC grids to avoid power congestion and to have natural power management[15][16].

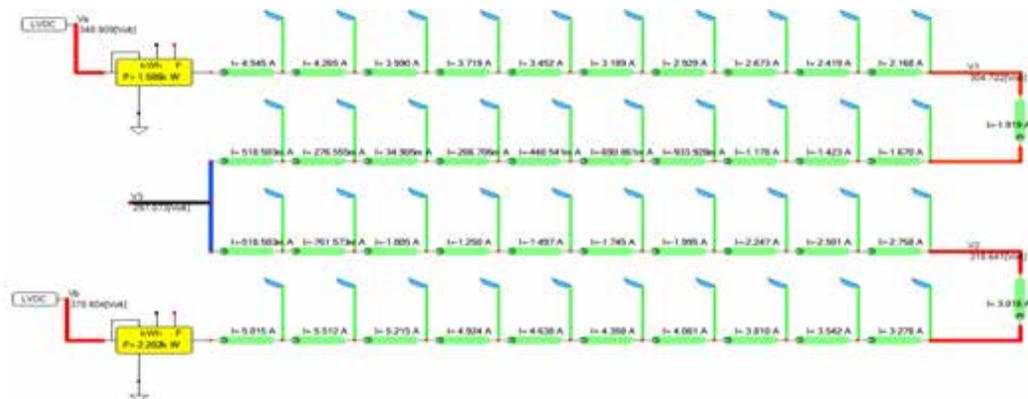


Figure 14. DC grid with 40 street lights each at 100 meters distance with a total length of 4km.

CONCLUSION

To investigate the application of DC grids in public street lighting, the influence of the cable in the DC grid for street lighting is discussed. In this paper, the retrofitting of the CombiCable for both AC and DC distribution is investigated and it is shown that the CombiCable can be used for combined AC and DC distribution. The main cores are used for the distribution of AC, while three auxiliary wires are used for DC distribution. The overall conclusion when retrofitting the CombiCable for combined AC and DC distribution is that the CombiCable can be used for combined AC DC power distribution. Reflections exist in the cable but are damped naturally and are not influencing the power distribution. Cross-coupling exist and can influence both distributions. It is shown that a pi section model is required to model the wave propagation and reflections in the cable. Retrofitting the existing AC cable where the auxiliary wires are used for the DC grid is possible, but the cross-coupling between the AC and DC grid in a single cable should not influence both grids. The simulations show that there is coupling between the AC and DC grid on the same cable. Disturbances due to the cross-coupling are performed in simulation and from this data the disturbance can be calculated. Final simulations show the application of a DC grid for feeding several kilometers of street lighting. Using droop control the power management in the DC distribution can be controlled naturally.

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THE FARM OF THE FUTURE

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ABSTRACT

The region of het Groene Hart in the Netherlands currently faces many issues, of which soil subsidence is the most urgent. The problems are mainly caused by the dairy industry, which covers 80% of the region. A fundamental change in land-use is therefore needed. In this paper first the Groene Hart region will be described and explored, after which the current issues will be presented. Next, different sustainable farming methods will be explored to find alternatives to the current land- use. Finally, natural building materials suitable to grow on peat soil will be described, which can be used to design a circular, zero-impact farm.

KEYWORDS

Het Groene Hart, peat, soil subsidence, sustainable farming methods, natural building materials

INTRODUCTION

This paper has been written to accompany research for my graduation project for the Architectural Engineering Graduation Studio. The project focuses on the context of ‘het Groene Hart’; a relatively green area in the middle of the Netherlands. The aim is to find a solution for the issues het Groene Hart currently faces, especially with regard to agriculture and sustainability. The final result will be the design of a zero-impact, circular farm; the construction of the building as well as the farm activities itself. This thematic research paper will therefore focus on the following question:

What sustainable farming methods can be used to grow building materials for the design of a circular, zero-impact farm in ‘het Groene Hart’ in the Netherlands?

To answer this question, several sub-questions are formed to seek answers to the different aspects of the research question. The sub-questions are:

- *What are current issues in het Groene Hart?*
- *Why is the current way of farming in het Groene Hart not sustainable?*
- *What types of sustainable & circular agriculture are there?*
- *What type fits best into the site of het Groene Hart?*
- *What natural building materials can be grown in het Groene Hart?*

This paper will first search for answers to the sub-questions, after a short introduction to the context.

HET GROENEHART

An introduction to ‘het Groene Hart’

‘Het Groene Hart’ (lit. translated: the green heart) is a relatively green area in the Netherlands, situated in between most of the big cities; Amsterdam, Rotterdam, The Hague and Utrecht (see: figure 1). The landscape nowadays functions for about 80% as grasslands for the dairy and meat industry, so the main view of the landscape looks like the image seen in figure 2 (Van den Akker et al., 2011). This ‘classic’ picture is probably how most tourists would picture the Dutch polder landscape, and this view is actually protected in het Groene Hart. Because of its central location, the housing shortage of the Randstad has been putting pressure on the borders of het Groene Hart for several decades. The area is relatively low populated but many regulations prevent new construction. More regulations prevent change in the landscape; one is not even allowed to just grow a ‘food forest’ on one’s own property in het Groene Hart; it is seen as a threat to the protected vistas. The landscape should remain the way it is now, open and empty. This need to keep the landscape the way it is now is remarkable, as het Groene Hart has actually always been changing, according to landscape architect Paul Plambeek (Voedsel families, 2020). The area has a long history and although many people view it as a natural area, people have been cultivating this landscape for over a thousand years, slowly sculpting it to their needs.



Figure 1: Image by author (Data resource: Qgis, Nationaal geo register)



Figure 2: Image by author

Het Groene Hart nowadays is almost entirely under sea level (see: figure 3). There are many different soil types in the area, of which peat is the most common (see: figure 4). Clay soil can be found around the rivers such as the Oude Rijn, Rotte and Hollandse IJssel. The little patches of nature spread throughout het Groene Hart predominantly have the character of peat meadows, swamps and marshlands.

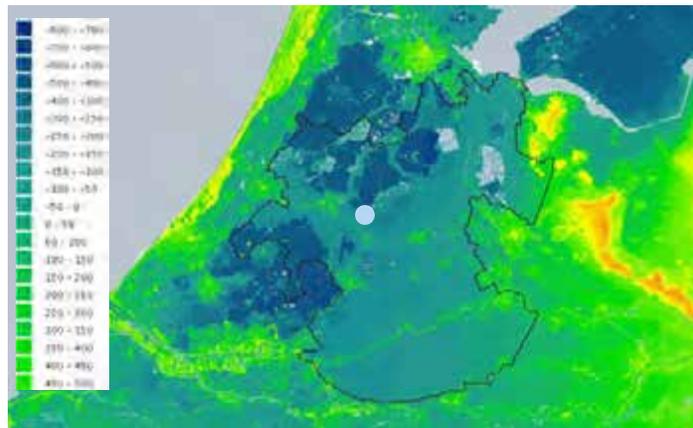


Figure 3: Image by author (Data resource: Qgis, Actueel Hoogtebestand Nederland)



Figure 4: Image by author (Data resource: Qgis, Nationaal geo register)

● Site choice

The history of het Groene Hart

About 3500 years ago, the formation of dunes on the coastline of the Netherlands caused for the swamps behind this coastal area to reach stable circumstances. This stagnated situation allowed peat to grow, sometimes multiple meters thick, in large parts of the Netherlands (Buro Sant en Co & FABRICations, 2019). The peat soils used to be located higher than sea level, before people started cultivating the landscape.

From the 10th century onwards, the population in the Netherlands was growing so fast that there was a need for new areas to live and to grow food (Pieterse, 2005). In het Groene Hart people started reclaiming the peatlands surrounding the rivers Maas and Rijn, by digging ditches to lower ground water levels so the land could be used for agricultural purposes.

In this way virtually the entire area of het Groene Hart is cultivated by the year 1300. Around het Groene Hart cities slowly emerged on higher grounds and in the 20th century these cities would form the Randstad (Amsterdam, Rotterdam, The Hague and Utrecht). By draining water from peat, however, peat starts to rot and the soil subsides, which causes wet soil again, making it necessary to drain more. Over the years the soils subsided so much that in large areas the soils became too wet for agriculture, so people started using the land to raise cattle on instead.

From the 12th century on people started extracting peat from the soil for energy production, leaving big craters in the landscape which turned into lakes eventually. These lakes were then drained again (in the 17th, 18th and 19th century) to gain more farmland (Pieterse, 2005). During the 19th and 20th century many dikes, pumping stations and other interventions were built to make sure the soil of het Groene Hart remained dry enough for cattle breeding. All these years of cultivating the landscape to meet the peoples' needs resulted in a soil subsidence of about 5 meters in just over a thousand years and over a hundred different artificially maintained water levels (Brouwer, 2018).

What are current issues in het Groene Hart? (Subquestion 1)

This long-term intensive cultivation of the landscape causes for a few serious problems, the soil subsidence being one of the most urgent. Almost the entire Groene Hart now lies under sea level (see: figure 3), with some parts being more than 6 meters below. This does not only result in high water management costs, but the lowest parts of het Groene Hart now also face another problem; salinization. Because of the drainage of these lower parts and the ongoing extraction of fresh water to keep the land dry enough for agriculture, salt water from deeper earth layers comes up and seeps into the area, causing for lower water quality, a higher fresh-water demand, loss in biodiversity and making the soil even less suitable for agriculture (Wit, et al., 1990). Moreover, soil subsidence also results in CO₂-emission. When the water in peat is drained, the soil oxidizes, sending carbon dioxide into the air and subsiding as a result (PLB, 2016). The CO₂-emission caused by peat oxidation in the Netherlands is now about 4,2 megatons a year. The sustainability goals of the government aim for a total CO₂-emission reduction to 11 megatons in total in 2050 (Buro Sant en Co & FABRICations, 2019). This means that if we don't do anything about soil subsidence in peatlands, almost half of our nationwide CO₂-emission by then will be emission caused by peat oxidation.

Soil subsidence in het Groene Hart is largely caused by artificially lowered water levels at the service of cattle farms (Van den Akker et al., 2011). By addressing this, one needs to discuss the other problems caused by this industry. This can be read in paragraph 2.4.

Another issue caused predominantly by the dairy/cattle industry is the loss of biodiversity in Het Groene Hart. Since over 80% of the current land use is now in service of the dairy industry, also about 80% of het Groene Hart consists of grasslands, which in turn exist almost entirely of one breed of grass: perennial ryegrass (Van den Akker et al., 2011). Conventional industrial agriculture also makes use of artificial fertilizer. Because of fertilizer, nitrogen levels are high in the soil of surrounding (natural) areas. This causes for a loss in biodiversity, as some species such as blackberries and stinging nettle who thrive on high nitrogen levels, take over (you can clearly see this in large parts of the Netherlands) (Stichting de Levende Natuur, 2019). This in turn has a direct effect on other flora and fauna in the food chain, thus reducing the biodiversity even more.

Lastly, climate change is starting to play its' role in the Groene Hart region. In certain areas within het Groene Hart salinization will get worse, and for large parts eutrophication (the process where water becomes too rich with nutrients, causing excessive algae growth and degradation of water quality) will occur more often. More frequent dry periods will cause desiccation of the peat soil, thus accelerating the soil subsidence and CO₂-emissions (Verhoeven et al., 2011).

The many issues discussed above call for action. The current approach of artificially maintaining low water levels in favour of the dairy industry does not work anymore, we have to find solutions to the issues and come up with a new proactive management plan. This does mean radical change for the current farming industry. Why this industry has to change anyways, will be discussed in the next chapter.

Why is the current way of farming in het Groene Hart not sustainable? (Subquestion 2)

One could argue that since the Netherlands is the second biggest exporter of food (by value), we don't have anything to complain about, only that we might try to make the current system a bit more sustainable (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019). However, exporting all your food out of the country might be good for the GDP but it doesn't necessarily mean that the Netherlands produces more food than it needs. In terms of sustainability, it is also very inconvenient to export 75% of the products Dutch farmers deliver, and then also import about 75% of the food the Dutch consume (Stichting LEI, Wageningen UR, 2011). The EU but also the Dutch government aim to create a more sustainable food and agriculture system and I believe this starts with closing loops within a country or region. Even though with our current diet there is not enough land to feed all Dutch, the Netherlands should strive to become more self-sufficient (Planbureau voor de Leefomgeving, 2019).

For het Groene Hart this means that the area needs to diversify. Currently about 80% of the entire Groene Hart is being used as grasslands for the dairy/cattle industry (Buro Sant en Co & FABRICations, 2019). This industry is quite problematic in itself. The issue is simple: milk is produced too much, and the price is too low (this is of course linked). Since WWII, governments worldwide have been motivating farmers to scale up and produce more, and more efficient. Dairy farmers nowadays own many hectares of land, hundreds of cows, and milking machinery costing millions. At the same time, people are consuming less and less dairy (Verandering voedingsmiddelen, 2016) and the dairy and meat industry proved to be one of the most polluting food industries. This is especially the case in Het Groene Hart, as here the issue is not only the methane-emission of cows, the manure surplus and the low calorie-production/land-needed ratio, but also the CO₂-emission by soil subsidence the dairy industry causes.

Nonsurprising, farmers are pressured to transition to more sustainable agriculture practices. However, most farmers do not have the economic resources to do so. The agricultural sector has a debt of 30 billion euros, according to Van der Ploeg from the Wageningen University (Meijer, 2019). Dairy farmers have to invest millions in heavy industrial machinery such as plows and automatic milking machines to be able to keep their head up in our current capitalist market. At the same time the industry is being overflowed with different regulations, subsidies and other rules to enable this market to remain the same. Most of the elderly Dutch will remember the “boterbergen en melkmeren” (lit. translated: buttermountains and milklakes) before the dairy produce quota was set in 1984 (Gov. UK, 2016). The dairy farmer finds himself in a locked-in system; his current way of farming is not profitable anymore, nor sustainable, but he cannot afford to change radically as he does not have the means to do so and could lose his subsidy.

In conclusion; dairy farming in het Groene Hart is not profitable, milk is being less consumed, the industry is too polluting; so, the main function of het Groene Hart needs to change radically. And as quoted from Regenerative farming (2020) “While [these examples show that] reducing negative impacts on individual issues is possible, this patchwork approach of addressing single problems only when they have reached critical levels cannot address fundamental, underlying causes of a system that is locked-in and needs fundamental change”.

What does this mean for the landscape of het Groene Hart?

As can be read in this chapter, het Groene Hart has important cultural and historical value. For new construction this means a lot of regulations and rules to be followed. A lot is being done to protect the region so that it remains the same. However, the current issues, soil subsidence being the most urgent, call for fundamental change in the use of the soil of het Groene Hart. The dairy farming industry is too polluting and not suitable for the vulnerable peat soil of the region.

There are different approaches to stop or slow down soil subsidence. Various methods are developed to prolong the viability of the dairy industry, such as subsurface drains (Querner et al., 2012). However, this is just a temporary reprieve and does not solve the issue in the long term. If the Netherlands wants to stop or slow down the soil subsidence significantly, water levels need to rise in het Groene Hart, meaning a wetland landscape less suitable for the dairy industry (Bureau Sant en Co & FABRICations, 2019). Aren't there more sustainable ways of farming, more suitable for het Groene Hart? Maybe it can keep its agricultural, open and natural character without aggravating current issues? Maybe the soil can regain its fertility, maybe there can be more space for water and biodiversity so unpredictable weather and changes in climate cause less damage.

In the fourth chapter different sustainable farming methods will be explored, to see which type suits best in a scenario where the Groene Hart region goes back to its natural state; of a wetland with higher water levels that are allowed to fluctuate with seasonal changes.

METHODS

The introduction to het Groene Hart was written using mainly online research and books as references. Field work is also implemented here: to get a good view of the region, I walked the Groene Hart path (192 km), where I experienced in real life the issues the area faces.

During this hike I interviewed various farmers and realised the complex locked-in system that challenges the future of agriculture. To find results on sustainable farming methods, I did mostly desk research; literature studies and case studies of sustainable farms. I also interviewed a few farmers

in the region that are farming (more) sustainable. Methods used to find results on natural building materials were; case studies on natural buildings, literature studies on natural building materials, literature studies on possible peat soil land-use, and desk study into the use of different crops as building materials. I also organised an excursion to Studio Tjeerd Veenhoven, where many different crops are used to design natural building materials. To find out more how these crops are cultivated, I organised an excursion with Roelof Westerhof to the Veenweide Innovatie Centrum (lit.translated: peat soil innovationcentre).

The methodology for this paper is visualised in the scheme below (figure 5).

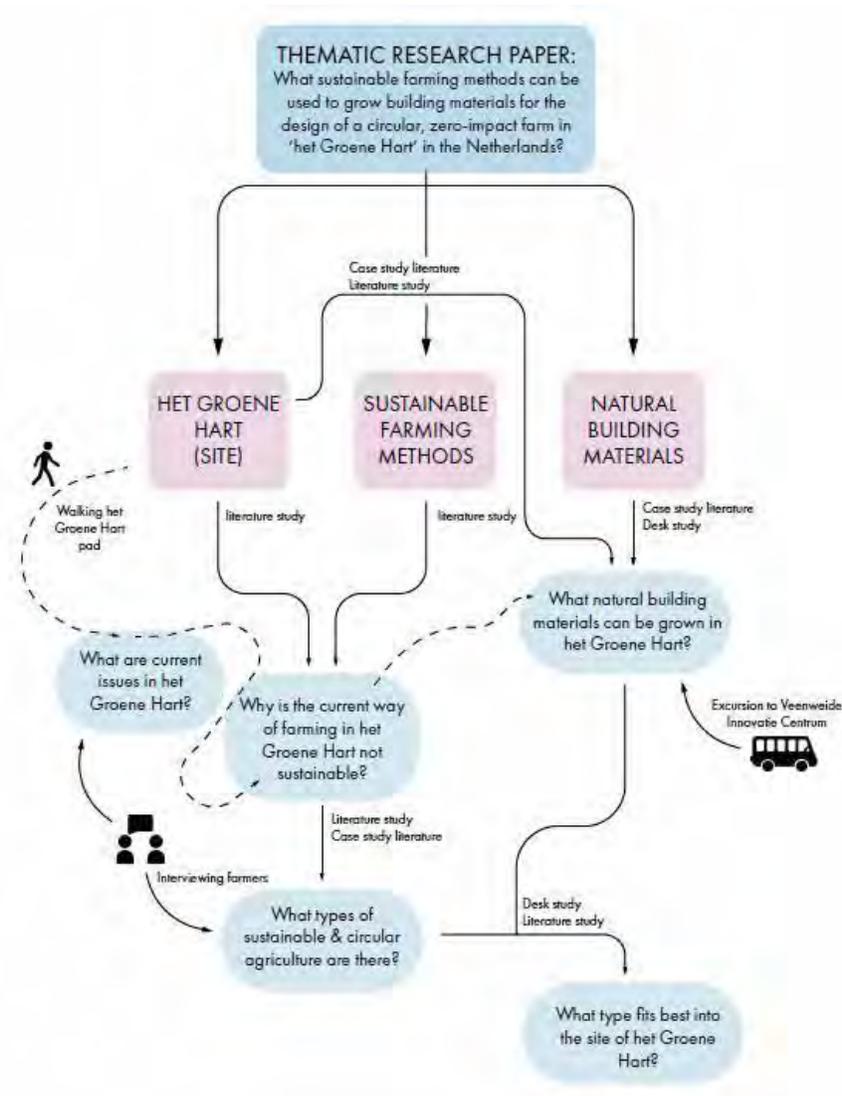


Figure 5: Diagram designed by author

RESULTS: SUSTAINABLE FARMING METHODS

What types of sustainable and circular agriculture are there? (Subquestion 3)

For this paper the following definition of sustainable agriculture will be used: “Sustainable agriculture is a way of practicing agriculture which seeks to optimize skills and technology to achieve long-

term stability of the agricultural enterprise, environmental protection, and consumer safety. It is achieved through management strategies which help the producer select hybrids and varieties, soil conserving cultural practices, soil fertility programs, and pest management programs. The goal of sustainable agriculture is to minimize adverse impacts to the immediate and off-farm environments while providing a sustained level of production and profit. Sound resource conservation is an integral part of the means to achieve sustainable agriculture” (Gold, 1994). As one can image, there is not one type of sustainable farming, and not one farm is the same. For this paper the focus will be on 6 types of sustainable, regenerative farming: permaculture, strip cropping, food forests, paludiculture, biodynamic farming and agroforestry. Let’s start with defining these agricultural systems.

Permaculture:

This term stems from permanent agriculture. Bill Mollison, the man behind the permaculture movement and inventor of the word, defines permaculture as “the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability and resilience of natural ecosystems” (Mollison, 1997).

Stripcropping:

This type of land-use is quite new, and has been developed by the Wageningen University. It is essentially a mix between conventional, industrial farming and a more regenerative type of farming. Instead of growing crops in massive fields, different types of crops are grown next to each other in large, narrow strips. This way the positive effects different types of crops have on each other (such as preventing plagues) are still achieved, but traditional machinery and harvest methods can still be used (Wageningen University, 2017).

FoodForests:

Food forests can be seen as permaculture in a more extreme way. Food forests are (mostly) planted forests with a high diversity of species. In general, little to no maintenance is needed. According to Francesca Riolo a food forest “provides ecosystem services typical of a tree system including making biodiverse fresh edible fruits, vegetables and herbaceous plant easily accessible to adults and children reconnecting them to healthy eating habits, food growing and the special experience of foraging and harvesting food directly from the plant in a nature-like setting” (Riolo, 2019).

Paludiculture:

In contrast to the other types of farming described in this chapter, paludiculture does not necessarily have a holistic approach. However, it is sustainable in the sense that it conserves peat soil and therefore prevents CO₂-emission. Paludiculture can be defined as growing crops and other biomass in wetlands (consisting of peat soil) (Abel et al., 2013).

Biodynamic farming:

Biodynamic farming is the only type of farming described which has patented certification. Steve Diver defines “the basic ecological principle of biodynamics is to conceive of the farm as an organism, a self-contained entity. A farm is said to have its own individuality. Emphasis is placed on the integration of crops and livestock, recycling of nutrients, maintenance of soil, and the health and wellbeing of crops and animals; the farmer too is part of the whole.” (Diver, 1999). Biodynamic agriculture has a highly holistic approach including rituals, following moon patterns etc.

Agroforestry:

According to Roger Leaky, agroforestry should be defined as: “a dynamic, ecologically based, natural resource management system that, through the integration of trees in farm- and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits” (Leaky, 2017)

As you might have noticed, these agricultural systems have a lot in common. One could conclude that the core value of these agricultural systems is to see your farmland as a live ecosystem that should be regenerative rather than a linear system where one just takes away from the land.

What type is most suitable for the site Het Groene Hart? (Subquestion4)

Although the agricultural systems described earlier have a lot of similarities, one system can be more suitable for the Groene Hart region than another.

Permaculture can basically be used everywhere, as it is a system that is based around the principle of enhancing natural ecosystems for production. Loops have to be closed within the ecosystem as much as possible. Biodynamic farming has a quite similar approach, so this method is also suitable. From personal experience however I learned that biodynamic farms are often quite labor-intensive, making it hard to gain profit.

Strip cropping is less suitable for the Groene Hart region as it still requires conventional heavy machinery, thus causing soil subsidence. A food forest could be interesting, but as the panoramic views in some areas of het Groene Hart are protected, growing high trees can be prohibited. Not many perennial edible species will survive on wet peat soil, thus reducing the potential diversity of edible species in a wetland food forest, and thereby its profitability. For growing building materials however, this system might be interesting as it might be possible to grow materials this way with little to no maintenance, and in the meantime enhance the natural state of peat ecosystems. Forests grow sediment and this stops soil subsidence, even promote regrowth of peat. Agroforestry has the same advantage, but it leans more to conventional farming, thus making it more interesting as a businessmodel. Paludiculture is interesting as it works with the wetland's natural resources and advantages.

Not one agricultural system can be addressed as being the most suitable for the Groene Hart region. Some systems have characteristics that are very useful however, so perhaps what will work best is 'the best of both worlds'; connecting different regenerative agricultural systems.

Permaculture works with 'zones', as seen in figure 6 (Mollison, 1997), which go from the most labour-intensive zone I (around the house), gradually to more 'natural' zones with less maintenance needed. This could mean that for example the zones around our farmhouse can be designed according to biodynamic or agroforestry principles, whereas zones further away can be designed as a food (or building material) forest, or practicing paludiculture. Another advantage of combining these systems is that this way there is more space for nature, it can enhance biodiversity and perhaps this way the farm can strengthen neighbouring natural areas. When combined with for example an educational function or a pick-your-own-garden, the farm can potentially also create more awareness and strengthen the relationship with people and their landscape. In the appendix in figure 1 an additional overview is added, where different possibilities of land-use on wet peat soil are presented.

What does this mean for architecture?

As can be read in the previous paragraph, there are various types of sustainable farming. After 6 agricultural systems were defined, a conclusion was made that these systems are quite similar, that there is not one perfect system for the Groene Hart region but that a mix of these systems might work well. If one would combine permaculture's zoning system with agroforestry, food forests and paludiculture, the landscape of the circular farm might look like the image seen in the appendix in figure 2. Because of the octagonal polder landscape and because it is convenient to have the farmhouse near a road, the zoning looks a bit different from the zoning Mollison originally designed. The Permaculture Designer's manual of founder Bill Mollison also describes in great detail the requirements for housing in a permaculture farm in humid, cool to cold climates (Mollison, 1997).

These requirements are mostly directed at creating a passive climate system, but when followed they will also have major consequences for the architectural image (for example, no windows on the west, a greenhouse facing south etc). The interpretation of the landscape of the farm also has direct consequences on the appearance of the farm itself, as it will be constructed with materials grown in this landscape. In the next chapter possible building materials that can be grown on peat soil will be discussed.

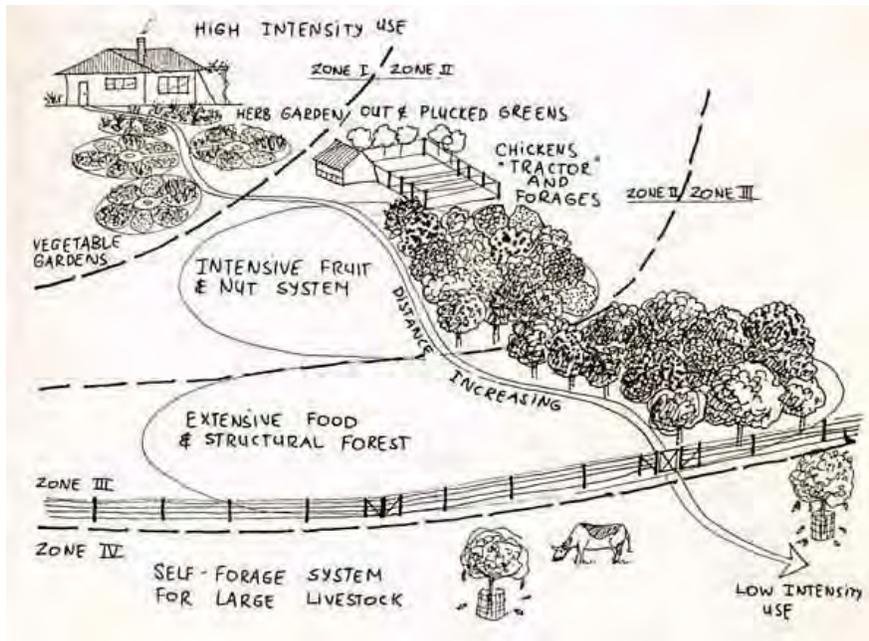


Figure 6: Permaculture zoning system. Source: Mollison, B. (1997). *Permaculture: A Designers' Manual*

RESULTS: NATURAL BUILDING MATERIALS

What natural building materials can be grown in Het Groene Hart? (Subquestion 5)

To create a circular, zero-impact farm, the construction should be designed of renewable materials, produced as local as possible. As the focus in this project is on the peat soil region of het Groene Hart, the variety in natural building materials that can be grown is limited. In figure 7 you can see an overview of building material crops that can be grown on peat soil. In figure 8 and 9 these materials are then categorised by growing time, durability and application possibilities. From this information we can draw conclusions about the suitability of different materials for various applications.

For what purposes do we need these different natural building materials?

From the ground up there are 6 categories of materials we need:

Foundation:

To design a foundation from natural building materials might be the biggest challenge of this project. This is especially the case because het Groene Hart consists predominantly of peat soil. (Buro Sant en Co & FABRICations, 2019). Large parts have a peat layer with a thickness of more than 2 meter, which makes it impossible to dig out the peat-soil until you hit more compact earth so you could replace the peat with compacted fill earth to create a stable foundation; a method used often when the peat layer is thin (Ibrahim et al., 2014, p. 10079). However, people have been building on peat soil for ages, so there are other possibilities. The “Rotterdamse methode” is commonly used historically in the Netherlands (de Vree, z.d.). The challenge with building foundations with wood is that the wood has to be under water entirely, otherwise it will rot. In the layer in between the wood underwater and the part above the water, needs to be insensitive to water (for example; the “Rotterdamse methode” uses brick on the border of water and air). This means it can't be made of a biodegradable component.

Loam or rammed earth are also sensitive to moist, so they are also not suitable. If the farm will have a traditional foundation, Black Elder can be used for the piles (it does not perish when completely underwater), but rock or bricks need to be sourced elsewhere.

Another method that can be used, it to construct a stilt house. A very durable wood is needed for this, as the stilts will be partly in peat soil, partly under water and partly above the weather, subject to heavy weather conditions. In Dutch waterworks, wood commonly used are Azobé, Larch and European

Oak (Centrum Hout, z.d.). Azobé is very durable and strong, but since it is a tropical species it is not desired in this project. Larch is indigenous, but does not grow well on peat soil. Oak does, even though it will grow slower when the soil is too wet. Accordingly, when a stilt construction will be used for the farm, oak is most preferred as construction material. Dirk Visser, foundations specialist from the TU Delft, informs me during a meeting that even though using this method will still mean the wood will rot eventually, one can design it in a way that it is easy to maintain and replace.

The whole building can also be designed to be floating on water, in which way oak should also be used, but the materials will need a lot of coating and maintenance, making this method less desirable. Finally, there are some experiments with 'creating' land by building a raft out of braided willow branches and filling it with dredged clay (see for example: <https://www.vanaalsburgbv.nl/legakker/>). Reed is then planted on the edges to prevent the islands' shore from slipping off. This is a very interesting way of building new (farm)land with only natural materials. However, it is not clear what the foundations of a building constructed on this type of 'artificial natural' land should look like.

Structural/load-bearing:

There are various natural building materials that can be used to build load-bearing structures. Wood is a very known material and can be used to build up to several levels. For peat soil crops this will be either Oak, Black Elder, Poplar or Willow. Straw is also a commonly used material in natural building, this crop functions as insulation but can also be used structurally (Post, 2013). Another low-tech solution is to braid reed stems into load-bearing arches (Watson, 2020), something that can also be done with willow branches. The disadvantage of using this as the load-bearing element is that the rest of the structure has to remain very light.

Insulation:

Many natural building materials that can be grown on peat soil have excellent insulation properties; hemp, reed, flax, straw and cattail just to name a few. Wood chips are a residual that have excellent thermal properties. The choice in material will come down to the manufacturing of the crop to material (low-tech to high-tech), the thermal resistance, and the place of use of the material (roof, wall or floor).

Exteriorfinish:

The most important property of an exterior finish is that it's water resistant. Depending on the material underneath it does not necessarily have to be entirely waterproof, but rain should be prevented from coming into the construction. For roofing, the most obvious material grown on peat soil is reed. Reed roofing has a long history in the Netherlands and has good thermal properties as well. For walls different materials are suitable. Reed can also be used vertically. Wood can be used in different shapes but it should be treated or protected from rain, otherwise it will perish quickly. When straw is being chosen as the main structure, the exterior finish could be a layer of loam (with clay sourced from nearby rivers), but this should be protected from too much rain. Another option is to use Peat blocks as exterior finish. Bioblocks sells 100% peat bricks from residual peat that's extracted from Dutch soil as a nature-preservation method. Perhaps this is also done in nature preservation in het Groene Hart and we can use this peat. However, this is a new market without much research output and results, and although peat has been used for exterior purposes for centuries (for example in a "plaggenhut", see image in figure 10), the durability of the material is uncertain.

A final option that can be looked into, is using mycelium bricks or panels. However, this material is relatively new on the market so not much is known about its durability and ability to survive heavy weather conditions.

Interiorfinish:

Wood is also suitable to use as an interior finish, in different shapes. Loam is a good way of creating a smooth, neutral interior wall. Another interesting option, quite new to the market, is to use biolaminates. These can be made of cattail, rye, reed, flax, wood chips and many other crops. As is seen during an excursion to Studio Tjeerd Veenhoven, who developed various biolaminates, one can use a natural adhesive as a binder, such as potato starch. The laminate could have a finish such as linseed oil to strengthen the material. A disadvantage of biolaminates is that they are not very durable. As the materials are quite new to the market, the durability is now set on at least 4 years according to Huis Veendam (Company New Heroes, 2019). Bamboo can also be grown on peat soil, yet it will not grow as fast or get as big as it can become in the tropics (Hol, 2019). Bamboo can be manufactured in beautiful panels. However, the manufacturing process is quite high-tech and a lot of glue is often used, making it less desirable to use.

Transparantsections:

To create transparent particles from natural building materials is very hard, if not impossible. There is recycled acrylic Perspex on the market (see: <https://www.pyrasied.nl/en/product/recycled-acrylic-greencast/>), but this does not have the thermal properties glass has. Linen, manufactured from flax, is a fabric that is also quite transparent and could be an interesting architectural element, but also does not have the right properties to function as windows. Perhaps the best option in this case would be to try to get recycled windows locally.

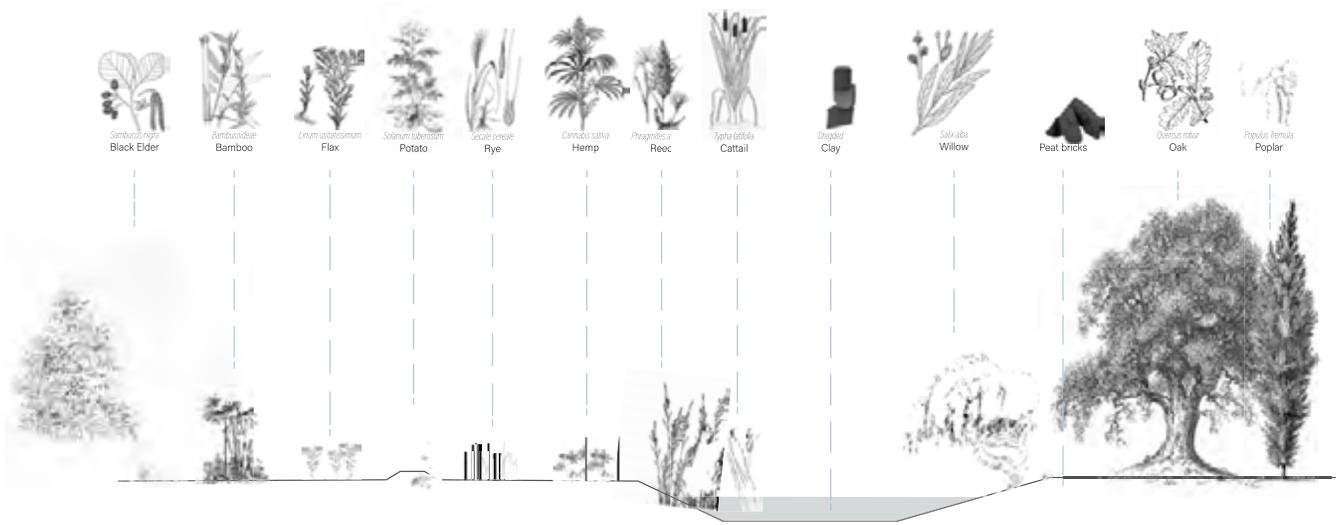


Figure 7: Natural building materials growing on peat soil (image by author)

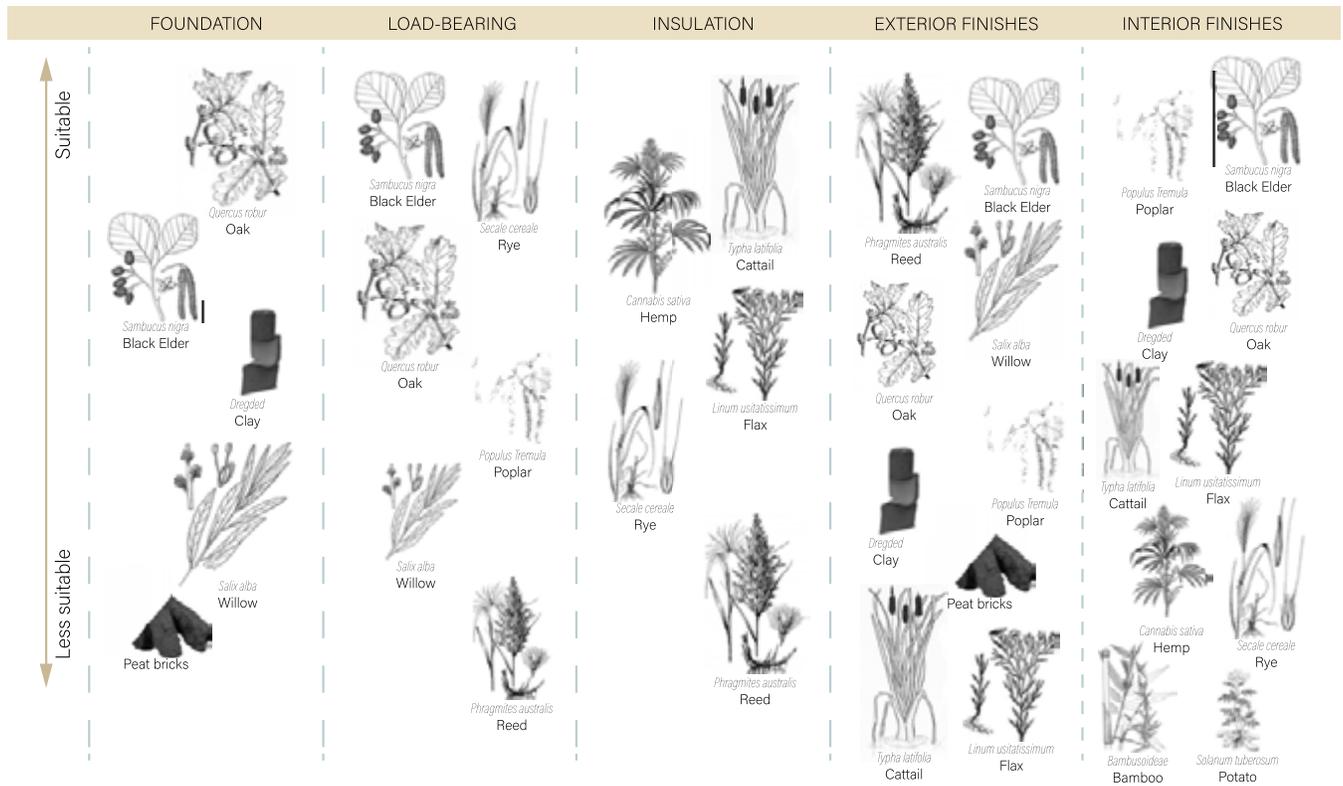


Figure 8: Natural building categorised by use (image by author)

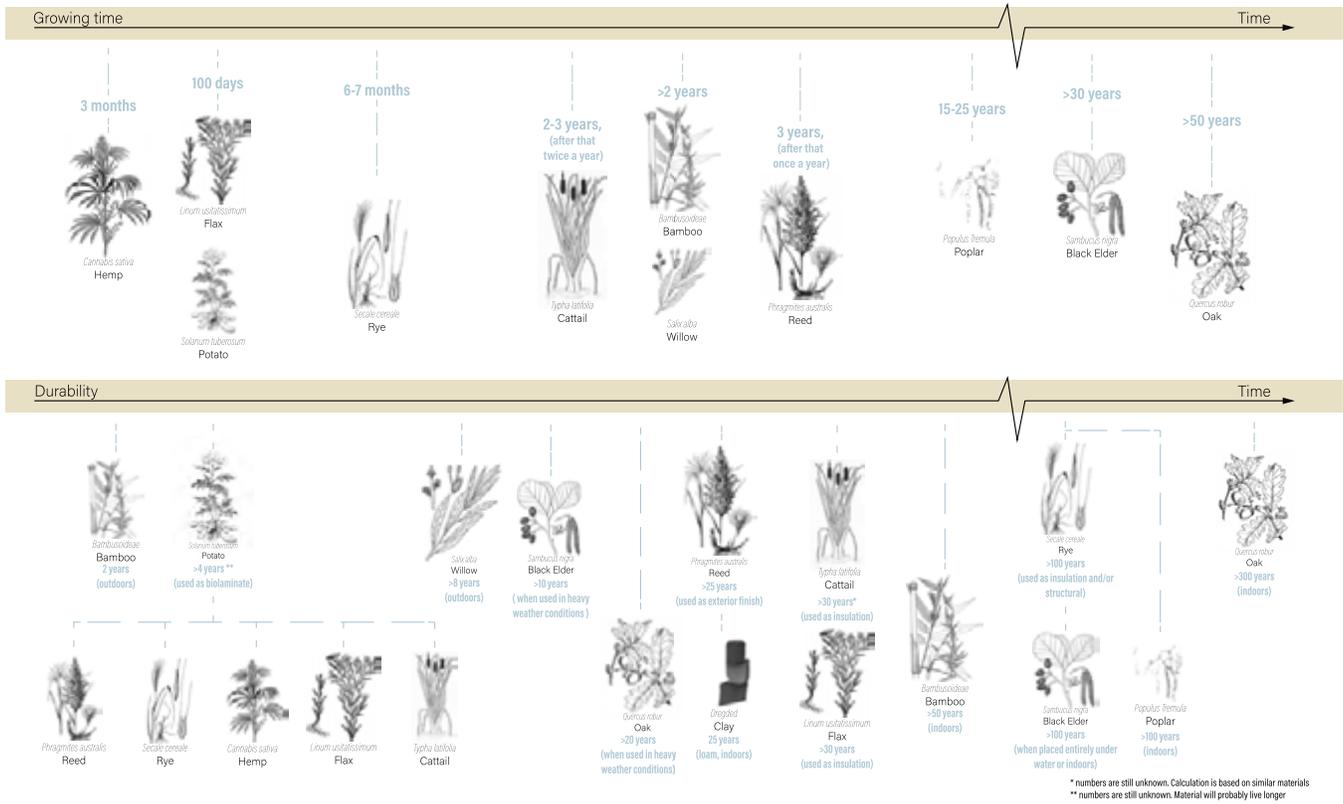


Figure 9: Natural building categorised by growing time and durability (image by author)

WHAT DOES THIS MEAN FOR ARCHITECTURE?

The architecture of the farm will be determined largely by the available natural building materials that can be grown, which is limited because of the peat soil of the Groene Hart region. As reed seems to be the most suitable material for roofing, the shape of the roof will have to be sloped in some way. Most natural exterior finishes are preferred to not get into too heavy weather conditions, thus making it necessary to create a cantilevering roof to protect the exterior wall materials. Because the aim is to create a building entirely composed of locally sourced materials, the whole construction will probably be built on a stilt foundation, which has a large impact on the appearance of the building. As glass cannot be sourced locally, the most sustainable option would be to source reusable recycled windows. As they already have set dimensions, this will have an impact on the appearance of the farm. Finally, using solely natural building materials will determine the overall colour scheme of the farm. However, this might be altered by using natural colouring.



Figure 10: Drentse plaggenhut. Source: Het grote boerderijenboek, Ben Kooij

DISCUSSION

The complex situation of issues in the agricultural locked-in system of het Groene Hart is not easy to solve. The solutions presented in this paper might seem straight forward but it is challenging to change the entire system. Agriculture in the Netherlands needs to become more sustainable but on the other hand the sector has invested so much in optimizing efficiency and production that fundamental change keeps being put off because of its risks and costs. The scenario that this paper is built upon, of raised water levels to slow down soil subsidence and a radical change in agricultural methods, might not become reality anytime soon even though it is urgent and necessary. The government is making plans to stop soil subsidence, but they are not very ambitious and are already contradicting the 2030 or 2050 goals (Atsma, 2020). An alarming trend in the Netherlands (and globally), is the rapidly dropping biodiversity. An investigation into one of the few natural reserves in 'het Groene Hart', the Nieuwkoopse plassen, shows the vast amount of endangered flora and fauna in this small area (see appendix, figure 3). This is another argument that our landscape needs to become more diverse, and that farming should be more in symbiosis with nature.

There is not much scientific research done on sustainable farming methods, as it is a practical craft and farming is subject to so many outside factors that it is difficult to gain hard data and strong evidence. As many farming methods have big overlaps in methods and approach, it is difficult to point out one clear system that will work best in the Groene Hart region.

Another point of discussion are the presented natural building materials that grow on peat soil. This can be a lot more elaborate, because there are many ways to till the soil to make it more suitable for different crops. An example for this is a rabattenbos, an ancient Dutch way of tilling the soil, where one digs a ditch and uses this soil to raise a bed next to the ditch, where many different types of trees can thrive on. Also, as Roelof Westerhof pointed out during the excursion to the VIC, the soil in het Groene Hart is not just peat but differs a lot from place to place, other types of soil such as clay are also found, thus creating different possibilities for crop growth. The thickness of the peat layer also differs a lot from place to place, creating different issues and opportunities everywhere.

Finally, the fundamental change that is needed to stop soil subsidence also calls for new, innovative ways of farming. At this point in time, the viability of a natural building material farm is very unsure and probably not profitable, according to Roelof Westerhof from the Veenweide Innovatie Centrum. However, this might change in the future if the government does start to actively promote a more sustainable Groene Hart, if local, sustainable food becomes more popular and wide-spread, or if natural building materials and its' locality become more appreciated.

CONCLUSION

As can be read in the first chapter, the many issues het Groene Hart currently faces, call for a fundamental change in the use of land. Dairy farming currently covers 80% of the land of het Groene Hart, while this industry at the same time is the main culprit of soil subsidence. Sustainable, regenerative farming methods are needed to reduce or stop the soil subsidence and its additional problems. When one has a final look at the question "What sustainable farming methods can be used to grow building materials for the design of a circular, zero-impact farm in 'het Groene Hart' in the

Netherlands?" one could conclude that there are many different sustainable farming methods and after exploring six different concepts, it was determined that not one type suits the Groene Hart region best. However, the permaculture concept mixed with methods of agroforestry, food forests and paludiculture perhaps will create the profitable, sustainable and regenerative landscape we are looking for to create a circular farm. In the fourth chapter different natural building materials were explored that grow on peat soil. A selection has been made to determine the most suitable materials for different purposes.

When constructing a building sourced entirely by locally grown natural building materials, it is obvious that these materials highly influence the appearance of the building. The durability of natural building materials is generally lower than for example concrete or steel, so frequent maintenance and/ or replacement is needed. To construct the building in a flexible way can facilitate this, and building adaptable in this fast-changing world might perhaps be an excellent idea anyways.

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APPENDIX

figure 1.1: Landscape possibilities on peat and clay soil with high and variable water levels



figure 1.2: Potential production chain of a natural building material farm

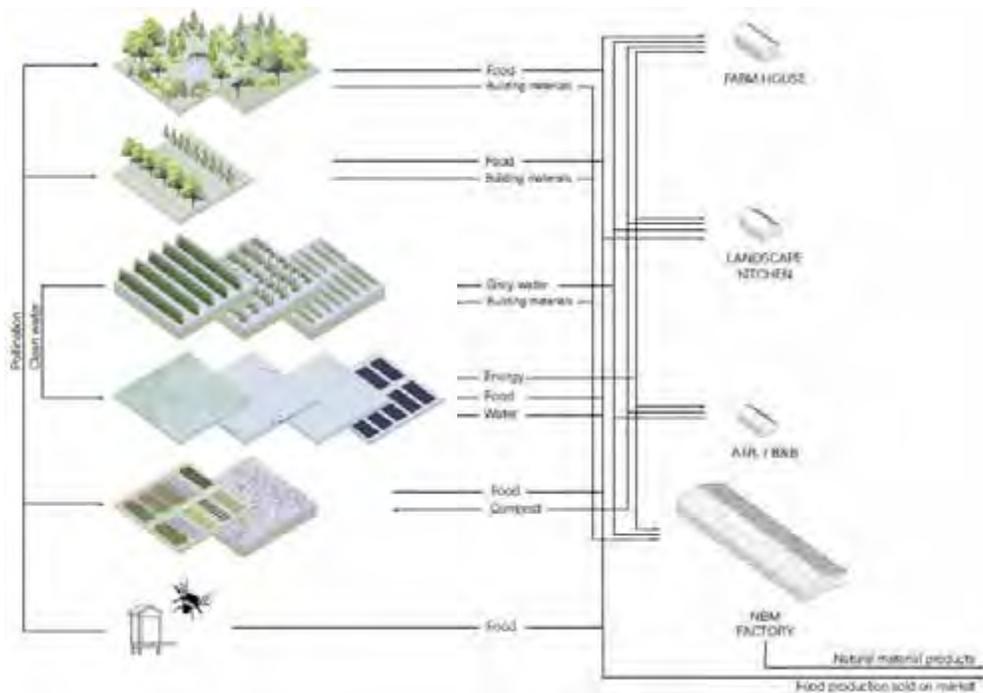


figure 2: Potential zoningsystem



figure 3: Endangered flora and fauna found in the Nieuwkoopse Plassen (on the Dutch red list)



BIJENORCHIS
Ophrys Apifera



BLAASVAREN
Cystopteris Fragilis



BOKKEN ORCHIS
Himantoglossum Hircinum



BREDE ORCHIS
Dactylorhiza Majalis



BRUINRODE WESPENORCHIS
Epipactus Atrorubens



MOERASWESPEN ORCHIS
Epipactis Palustris



POPPEN ORCHIS
Ophrys Anthropophora



RIET ORCHIS
Dactylorhiza Praetermissa



VEENMOS ORCHIS
Hammarbya Paludosa



VLEESKLEURIGE ORCHIS
Dactylorhiza Incarnata



TONGVAREN
Asplenium Scolopendrium



BLAUWE ZEEDISTEL
Eryngium Maritimum



GELE HELMBLOEM
Pseudofumaria Lutea



GULDEN SLEUTELBLOEM
Primula Veris



HARLEKIJN
Anacamptis Morio



KLOKJESGENTIAAN
Gentiana Pneumonanthe



SLANKE GENTIAAN
Gentianella Amarella



KRUISBLAD GENTIAAN
Gentiana Cruciata



VELDGENTIAAN
Gentianella Campestris



KLUWENKLOKJE
Campanula Glomerata

figure 3: Endangered flora and fauna found in the Nieuwkoopse Plassen (on the Dutch red list)



DASLOOK
Allium Ursinum



GEVLEKTE ORCHIS
Dactylorhiza Maculata



GROENE KNOL ORCHIS
Liparis Loeselii



GROTE KEVER ORCHIS
Neottia Ovata



HONING ORCHIS
Herminium Monorchis



WATERDRIEBLAD
Menyanthes Trifoliata



WELRIEKENDE NACHT ORCHIS
Menyanthes Trifoliata



RECHTE DRIEHOEKSVAREN
Gymnocarpium Robertianum



SCHUBVAREN
Asplenium Ceterach



STEENBREEKVAREN
Asplenium Trichomanes



HONDSKRUID
Anacamptis Pyramidalis



JENEVERBES
Juniperus Communis



KLEIN GLASKRUID
Parietaria Judaica



KLEINE ZONNEDAUW
Drosera Intermedia



RONDE ZONNEDAUW
Drosera Rotundifolia



LANGE EREPRIJS
Veronica Longifolia



MUURBLOEM
Erysimum Mauve



PARNASSIA
Parnassia Palustris



PRACHTKLOKJE
Campanula Persicifolia



RAPUNZELKLOKJE
Campanula Rapunculus

figure 3: Endangered flora and fauna found in the Nieuwkoopse Plassen (on the Dutch red list)



RUIG KLOKJE
Campanula Trachelium



SPAANSE RUITER
Cirsium Dessectum



STEENANJER
Dianthus Deltoides



STENGELLOZE SLEUTELBLOEM
Primula Acaulis



STIJF HARDGRAS
Catapodium Rigidum



WILDE MARJOLEIN
Origanum Vulgare



ZOMERKLOKJE
Leucojum Gravetye



ZWARTSTEEL VAREN
Asplenium Adiantum



BITTERVOORN
Rhodeus Amarus



KLEINE MODDERKRUIPER
Cobitis Taenia



KAMSALAMANDER
Triturus Cristatus



POELKIKKER
Pelophylax Lessonae



RUGSTREEPPAD
Bufo Calamita



GESTREEPTE WATERROOFKEVER
Graphoderus Bilineatus



GROENE GLAZENMAKER
Aeshna Viridis



GRAUWE KIEKENDIEF
Circus pygargus



KEMPHAAN
Philomachus pugnax



KWAK
Nycticorax nycticorax



WOUDAAP
Ixobrychus minutus



GROTE KAREKIET
Acrocephalus arundinaceus

figure 3: Endangered flora and fauna found in the Nieuwkoopse Plassen (on the Dutch red list)



VALKRUID
Arnica Montana



VELDSALIE
Salvia Pratensis



WILDE GAGEL
Myrica Gale



HERFSTTIJLOOS
Colchicum Autumnale



WILDE KIEVITSBLOEM
Fritillaria Meleagris



MEERVAL
Silurus Glanis



RIVIERDONDER PAD
Cottus Perifretum



KROESKARPER
Carassius Carassius



VETJE
Leucaspius Delineatus



HEIKIKKER
Rana Arvalis



ZANDHAGEDIS
Lacerta Agilis



RINGSLANG
Natrix Natrix



MUURHAGEDIS
Podarcis Muralis



DWERGMEEUW
Hydrocoloeus minutus



GRAUWE GORS
Emberiza calandra



KWARTELKONING
Crex crex



PIJLSTAART
Anas Acuta



WATERSNIP
Gallinago gallinago



ZOMERTALING
Anas querquedula



ZWARTE STERN
Chlidonias niger

figure 3: Endangered flora and fauna found in the Nieuwkoopse Plassen (on the Dutch red list)



KOEKOEK
Cuculus canorus



PATRIJS
Perdix perdix



PORSELEINHOEN
Porzana porzana



ROERDOMP
Botaurus stellaris



SLOBEEND
Spatula clypeata



GRASZANGER
Cisticola juncidis



KLEINE ZILVERREIGER
Egretta garzetta



KLEINST WATERHOEN
Porzana pusilla



MATKOP
Poecile montanus



OEVERLOPER
Actitis hypoleucos



ZEEAREND
Haliaeetus albicilla



KLEVERIGE POELSLAK
Myxas glutinosa



GLADDE SCHIJFHOREN
Gyraulus laevis



KLEIN SCHORSHORENTJE
Balea perversa



FIJNGERIBDE GRASSLAK
Backeljaia gigaxii



KONIJN
Oryctolagus cuniculus



LAATVIEGER
Eptesicus serotinus



NOORDSE WOELMUIS
Microtus oeconomus



OTTER
Lutrinae Mustelidae



ROSSE VLEERMUIS
Nyctalus noctula

figure 3: Endangered flora and fauna found in the Nieuwkoopse Plassen (on the Dutch red list)



SNOR
Locustella luscinioides



WIELEWAAL
Oriolus oriolus



WINTERTALING
Anas crecca



BRILDUIKER
Bucephala clangula



BUIDELMEES
Remiz pendulinus



ROODHALSFUUT
Podiceps grisegena



ROODMUS
Carpodacus erythrinus



SMIENT
Mareca penelope



STELTKLUUT
Himantopus himantopus



VISDIEF
Sterna hirundo



KNOTWILGSLAK
Clausilia dubia



TWEEELING BARNSTEENSLAK
Oxytoma sarsii



BOOMMARTER
Martes martes



BUNZING
Mustela putorius



HERMELIJJN
Mustela erminea



TWEEKLEURIGE VLEERMUIS
Vespertilio murinus



WATERSPITSMUIS
Neomys fodiens



WEZEL
Mustela nivalis

Sources consulted for this overview:
<https://minez.nederlandsesoorten.nl/content/rode-lijsten>
& <https://www.verspreidingsatlas.nl>

SOCIO-CULTURAL CONDITIONS

The city provides access to lifelong education for all and facilitates conditions for vibrant human expression, knowledge, interaction and governance by promoting cultural activities and full community participation. It invests in an equitable economy that benefits people and planet and is committed to the wellbeing of every citizen, regardless of socioeconomic status.



THE ROLE OF LIVING-LABS IN CITIES' TRANSITION TO A CIRCULAR ECONOMY

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ABSTRACT

The paper aims to emphasize the role of living-labs in cities' transition to a circular economy (CE). The paper purpose was addressed by an analyse different types of living-labs. The circular economy concept is an umbrella concept that has grown in recent years, both globally and locally, being increasingly addressed through measures, policies and rules. CE is a sustainability paradigm that has the goal to harmonize the sustanability pillars: economic, environment and social.

Currently more than half of the world's population lives in cities, while forecasts show a two-thirds increase by 2050 (70%), in addition 75% of global natural resources and 80% of global energy supply are consumed by cities, so that there is a growing need for a transition to a sustainable society.

A living-lab is a system or a consortium of stakeholders, based on open innovation, which is meant to solve a problem the stakeholders face in the society.

The analyse showed that the principal focus of the living-labs model is on the folowing subjects: green, smart mobility, building standards, efficient use of resources, energy conservation, social and economic equity and waste management.

The studied model shown that the living-lab concept is an appropriate instrument of CE to meet the sustainable development goals.

KEYWORDS

circular economy, living-lab, urban living lab, circular cities.

INTRODUCTION

In the twenty-first century, society is confronted with unprecedented difficulties, including a climate emergency, ecosystem degradation, worldwide urban migration, pandemics, and economic change fueled by new technology. These issues are complicated and interwoven, need immediate action at the local, regional, and global levels. Implementing a living lab can be the best approach.

A living lab is a physical or virtual venue where many stakeholders are brought together for collaboration and collaborative ideation in order to tackle societal concerns, particularly in urban regions. Despite the fact that scholars, practitioners, and policymakers are paying more attention to the concept, many people are still confused about what it means [1]. The definition we will refer during his research is:

Living labs are physical or virtual venues and human systems where we create, test, research, and learn from social and technological breakthroughs in real-time, real-world settings. They encourage collaborative experimentation, innovation piloting, critical evaluation of results, and information sharing [1].

Inhabitants are increasingly being involved in city development in order to make cities more flexible to citizens' requirements. It is critical to evaluate the long-term effects of, for example, climate-related problems in cities such as air pollution, flooding, and so on, as well as the social ramifications of the remedies we have implemented in our cities. To handle such complicated issues, we must enlist the help of not just citizens, but also businesses, research communities, and educational institutions, as well as the governmental sector [2].

Academic writing on living labs can be separated into two streams that are mutually beneficial. The first stream is primarily theoretical, and regards the 'Living Lab' as a methodology for innovation, referring to living labs as a model or methodology [3] [4]. The second stream of literature, which is concerned with the organization of innovation through living labs, looks at how this paradigm is really implemented. This second stream characterizes living labs as environments [5], milieus [6] or systems [7].

CIRCULAR ECONOMY AND LIVING LABS

There are many definitions of Circular Economy in the literature, but the one we will refer to in this articles is the one developed on a review of circular economy definitions in 2017[1]. An economic system that substitutes the concept of "end-of-life" with reducing, reusing, recycling, and recovering resources in the production, distribution, and consumption processes. It works at the micro (products, firms, consumers), meso (eco-industrial park), and macro (city, region, nation, and beyond) levels to achieve sustainable development, resulting in improved environmental quality, economic prosperity, and social equality for present and future generations. It is enabled by novel business models and responsible consumers" [8].

The current linear paradigm of production and consumption in modern society is unsustainable, and urgent changes are required to solve the socioeconomic concerns of population growth and an expanding middle class [9]. The circular economy (CE), which strives to eliminate waste, increase resource value, reduce negative effects, and build economic, environmental, and social capital [9],[10], is gaining steam as a possible solution to these issues.

Living laboratories are a relatively new type of open innovation network that offers a variety of research options [11]. Multiple fields and concepts are examined in living labs, including the transition to low-carbon economies, experimental governance, and novel approaches to sustainable development [12].

In the production of new technologies, services, goods, or systems, a living lab stresses the responsibilities of user interaction, prototyping, testing, and validating in real-world contexts [13]. Living labs use an experimental approach to co-creation, involving public-private-people relationships.

Urban living labs are increasingly being used for environmental sustainability and circular economy, with the goal of regenerating neighborhoods, supporting circular businesses, facilitating circular experimental tenders, and allowing the testing of decentralized waste recovery systems [14].

2.1 Urban living labs in cities

Sustainably oriented urban city laboratories can operate as a unique circular economy environment [15].

Cities, with their inventive capabilities, are crucial locations for addressing serious climate, environmental, and health issues. Living Labs, for example, can serve as a starting point for reintroducing resources into the production cycle and reducing environmental consequences, embracing the circular economy model (CE).

In particular, as a form of policy lab, Urban Living Labs (ULL) offer prospects for increased spread of sustainability transitions and are characterized by stakeholder collaboration and experimentation [16] [17].

According to research, ULLs frequently address concerns of sustainability and mobility in order to make cities more sustainable [18].

RESEARCH METHOD

This study aims to see how living labs can facilitate the transition to a more circular economy. We also wanted to see how this paradigm is implemented and analysed in academic research. To do so, we combed through the most important scientific papers in the Web of Science database. Our goal is to look at all of the living labs mentioned in the research papers in order to gain a better understanding of the current university context and how this new approach might aid in the implementation of circular economy approaches.

In order to do this review we used the stages suggested by Kitchenham (2004) and adapt them in order to perform a systematic review: 1. Planning the review, 2. Conducting the review and 3. Reporting and dissemination.

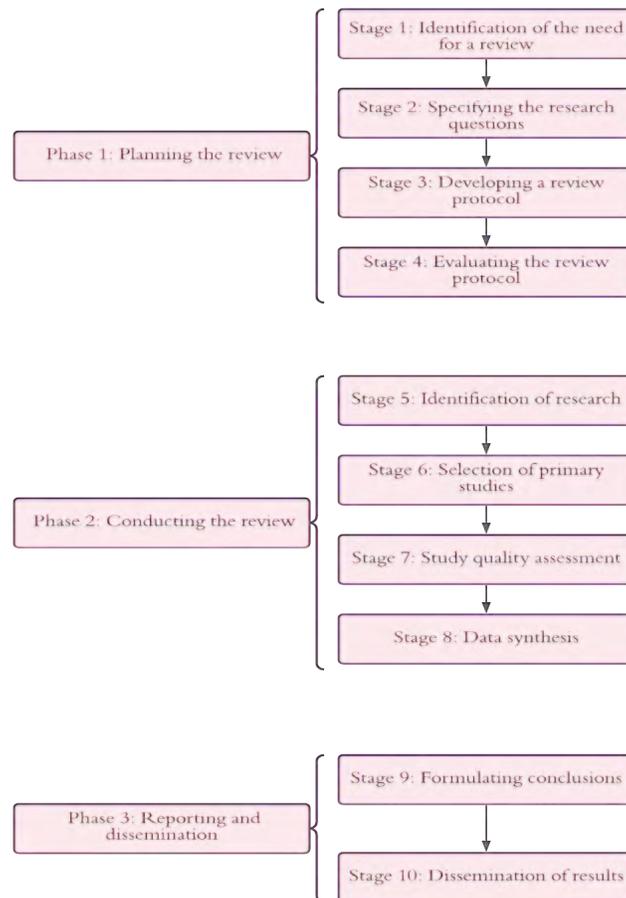


Figure 1. Systematic review steps adapted from Kitchenham (2004) [19]

A review of the literature on the Web Of Science (WOS) search engine was done to provide an overview of how the scientific community responds to methodological challenges in order to create living labs. The search was limited to (1) scientific articles or book chapters published in English between 2010 and 2021, (2) relevant topics (living labs, circular economy, green, smart mobility, building standards, efficient use of resources, energy conservation, social and economic equity and waste management), and (3) comparisons between existing living labs. The current study did not take into account metrics that were available online but did not have a published methodological underpinning.

This research, which is organized as a review of living labs for the purpose of implementing the circular economy, included an extensive search to look at different sorts of living labs. Following the search, a screening process was carried out, which involved reviewing the title and synopsis of each result.

The search yielded 1,820 items, however only 155 were deemed the most representative after the initial screening step. We read the abstracts of every article selected in the first phase in the second step of the screening process and decided to delete studies that did not directly address the issue of living labs and circular economy components or showed a high similarity to other articles already included in the review. Following that, we're left with 38 publications that best answer our research query.

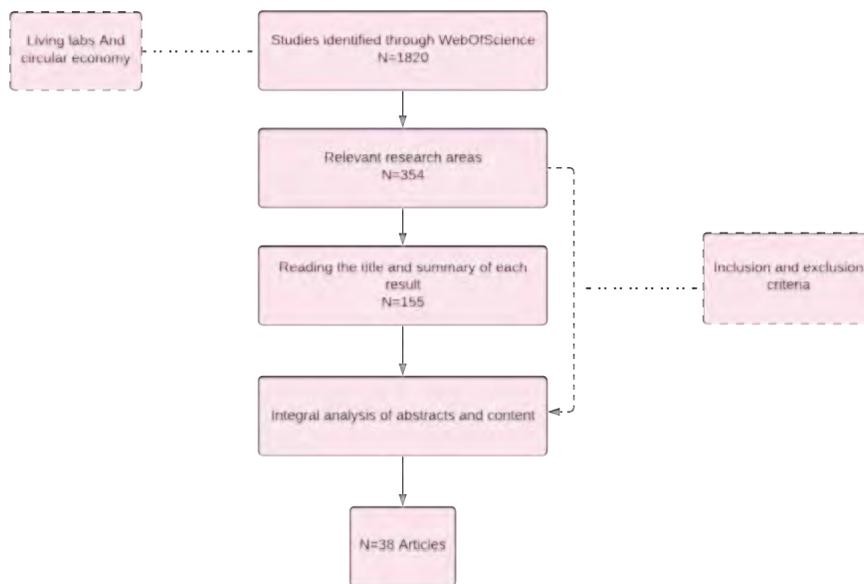


Figure 2. The study selection process

RESULTS OF THE REVIEW

We found out during this research that only few articles are referring to living lab and circular economy. But when we were looking for concepts like green, smart mobility, building standards, efficient use of resources, energy conservation, social and economic equity and waste management we found more research. Thus all the articles included in the review are related to circular economy components even if the link is not evident and highlighted.

During our study, we discovered that practically almost all of the living lab publications we saw referred to campus as a living lab.

According to the definition “A Campus as Living Lab is an integrated organizational, technological, and socio-economic approach in which a university uses its assets and facilities to study, test, or demonstrate novel technologies or services by, with, and for its community” [20]. It’s referred to as Campus as a Sustainability Living Lab when the ideas being evaluated are concerned with sustainability. These Living Labs bring together teaching, research, and campus operations in one place.

The Campus as a Living Lab allows for the identification of very relevant and significant challenges while also providing a pedagogical framework in which students are truly motivated, involved, and prepared to address a variety of issues involving

not only academia but also government, citizens, and industry. As a result, students can apply their theoretical knowledge to come up with practical answers to problems in such situations [21].

As a result, they can serve a variety of purposes and be used in a variety of settings. For example, at an Egyptian architectural university, they tried to use urban living lab concepts as part of the pedagogical process to establish a distinct educational technique for teaching green sustainable design. In this scenario, they used a real-life environment to give students an integrated understanding of site, climate, and sustainable building design concepts, as well as an understanding of the cultural and social human dimensions of new construction [22].

Because of the things mention above there are a lots of campuses as a living labs initiatives. Some examples are: MIT Office of Sustainability (MITOS), The Green Village at TU Delft, Harvard Living Lab initiative, UBC’s Campus as a Living Lab (CLL), The University of Alberta and many more.

Also we found out that urban experiments, such as Living Labs in the subject of circular economy, are critical for developing innovative long-term policies by identifying new products, platforms, and solutions.

In urban contexts, a Living Lab is defined as an innovative policy instrument that allows people to participate in the entire development process as users and co-creators by exploring, examining, experimenting, testing, and evaluating new ideas and creative solutions in complex and everyday situations. Municipalities can act as a promoter, enabler, or partner in Living Labs, with the ultimate goal of understanding how to strengthen transformative urban policies on sustainability and CE [23].

Regarding Public Sector, Living labs contribute to increasing the area for innovation and experimentation, expanding the repertoire of methodologies utilized, and giving a way to rethink and differentiate between diverse forms of public sector innovation outcomes. Living labs appear to disrupt traditional forms of public invention by focusing much more on various forms of co-creation of innovation, particularly through involving users and other stakeholders directly or indirectly in experimental forms of innovation [24].

CONCLUSIONS

In a constantly changing world where virgin resources are increasingly limited, it is necessary to transition to a circular operating system. The way we can make this transition has been studied from different perspectives. In the present study, the focus is on living labs as a system to facilitate the transition to a circular economy.

Only a few papers explicitly address the circular economy concept, despite the fact that we uncovered elements connected to the circular economy in all of the articles examined in this study. So, perhaps because there are too many definitions of circular economy and no agreed-upon definition in the research community, and also because living labs are not clearly defined and we found varied perspectives on them.

Future studies should explore the living labs activities regarding the 10R of circular economy to see if all of them are addressed by now or which one is more explored. In order to see exactly what works best or on which components this type of living lab approach best fits, it is important to have some research that aims at what currently exists according to the EC principles.

APPENDIX A

| No. | Authors | Article Title | Journal | Year |
|-----|---|---|-------------------------------|------|
| 1 | Huertas, Jose I.; Mahlknecht, Juergen; Lozoya-Santos, Jorge de J.; Uribe, Sergio; Lopez-Guajardo, Enrique A.; Ramirez-Mendoza, Ricardo A. | Campus City Project: Challenge Living Lab for Smart Cities | APPLIED SCIENCES-BASEL | 2021 |
| 2 | Tyl, Benjamin; Allais, Romain | A design study into multi-level living labs for reuse and repair activities in France | JOURNAL OF CLEANER PRODUCTION | 2021 |

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|----|--|--|---|------|
| 3 | Sarkilahti, Maarit; Akerman, Maria; Jokinen, Ari; Rintala, Jukka | Temporal challenges of building a circular city district through living-lab experiments | EUROPEAN PLANNING STUDIES | 2021 |
| 4 | Kretschmer, Sebastian; Dehm, Sheena | Sustainability Transitions in University Food Service-A Living Lab Approach of Locavore Meal Planning and Procurement | SUSTAINABILITY | 2021 |
| 5 | Fuglsang, Lars; Hansen, Anne Vorre; Mergel, Ines; Rohnebaek, Maria Taivalsaari | Living Labs for Public Sector Innovation: An Integrative Literature Review | ADMINISTRATIVE SCIENCES | 2021 |
| 6 | Mazurek, Damian; Czapiewski, Konrad | What Solutions for Waste Management? Issues of Flows and Governance Exemplified by the Lodz Agglomeration (Poland) | ENERGIES | 2021 |
| 7 | Tolentino-Zondervan, Frazen; Bogers, Enide; van de Sande, Luc | A Managerial and Behavioral Approach in Aligning Stakeholder Goals in Sustainable Last Mile Logistics: A Case Study in the Netherlands | SUSTAINABILITY | 2021 |
| 8 | Compagnucci, Lorenzo; Spigarelli, Francesca; Coelho, Jose; Duarte, Carlos | Living Labs and user engagement for innovation and sustainability | JOURNAL OF CLEANER PRODUCTION | 2021 |
| 9 | Engez, Anil; Leminen, Seppo; Aarikka-Stenroos, Leena | Urban Living Lab as a Circular Economy Ecosystem: Advancing Environmental Sustainability through Economic Value, Material, and Knowledge Flows | SUSTAINABILITY | 2021 |
| 10 | Cuomo, Federico; Lambiase, Nadia; Castagna, Antonio | Living lab on sharing and circular economy: The case of Turin | HEALTH INFORMATICS JOURNAL | 2021 |
| 11 | Greve, Katharina; De Vita, Riccardo; Leminen, Seppo; Westerlund, Mika | Living Labs: From Niche to Mainstream Innovation Management | SUSTAINABILITY | 2021 |
| 12 | Lupp, Gerd; Zingraff-Hamed, Aude; Huang, Josh J.; Oen, Amy; Pauleit, Stephan | Living Labs-A Concept for Co-Designing Nature-Based Solutions | SUSTAINABILITY | 2021 |
| 13 | Bhavsar, Rutul; Cupido, Anthony; Arriaga, Mariano | MOHAWK COLLEGE'S NET ZERO ENERGY AND ZERO CARBON BUILDING-A LIVING LAB FOR HIGH EFFICIENCY AND RENEWABLE ENERGY TECHNOLOGIES IN BUILDINGS | JOURNAL OF GREEN BUILDING | 2020 |
| 14 | Cerreta, Maria; Elefante, Alessia; La Rocca, Ludovica | A Creative Living Lab for the Adaptive Reuse of the Morticelli Church: The SSMOLL Project | SUSTAINABILITY | 2020 |
| 15 | Obersteg, Andreas; Arlati, Alessandro; Knieling, Jorg | MAKING CITIES CIRCULAR: EXPERIENCES FROM THE LIVING LAB HAMBURG-ALTONA | EUROPEAN SPATIAL RESEARCH AND POLICY | 2020 |
| 16 | Greer, Rachel; von Wirth, Timo; Loorbach, Derk | The diffusion of circular services: Transforming the Dutch catering sector | JOURNAL OF CLEANER PRODUCTION | 2020 |
| 17 | Cuomo, Federico; Ravazzi, Stefania; Savini, Federico; Bertolini, Luca | Transformative Urban Living Labs: Towards a Circular Economy in Amsterdam and Turin | SUSTAINABILITY | 2020 |
| 18 | Abdullah, Jamalunlaili; Ahmad, Raziah; Zaina, Muhammad Hafiz | The Blue-Green Urban Living Labs of Kuala Lumpur | ENVIRONMENT-BEHAVIOUR PROCEEDINGS JOURNAL | 2020 |
| 19 | Pucihar, Andreja; Zajc, Iztok; Sernec, Radovan; Lenart, Gregor | Living Lab as an Ecosystem for Development, Demonstration and Assessment of Autonomous Mobility Solutions | SUSTAINABILITY | 2019 |

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BUT FIRST FOOD: GRASSROOTS FOOD INITIATIVES DURING THE COVID-19 PANDEMIC IN THE GERMAN COLOGNE-BONN REGION

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ABSTRACT

The COVID-19 pandemic has shaped the way citizens perceive their food environment, catalysing the surge of innovative solutions that answer these new perspectives. The crisis has significantly shifted consumption and eating habits in Germany, increasing the demand for regionally produced and organic products and those made under animal welfare standards, climate, and biodiversity protection. As a result, many existing grassroots food initiatives (e.g., community-supported agriculture (CSA), food assemblies) enjoyed high reactivation and great acceptance at the same time novel initiatives popped up to supply the demand for these products, such as a boost in e-commerce in the form of regional food delivery boxes, new forms of food distribution, and an increase in at-home food production. Through an exploratory analysis, this study aims to understand better how grassroots initiatives in the Cologne-Bonn region in Germany used their potential for innovations and responded to the current health crisis and the lessons learned to promote and enhance changes to more resilient and sustainable urban food systems through a grassroots innovation analysis lens.

KEYWORDS

food systems, COVID-19, local, regional, social initiatives, food assembly, CSA, food start-ups, regional food delivery boxes, e-commerce

INTRODUCTION

COVID-19 pandemic has reached every aspect of human life, facing society to complex challenges; at the global level, according to [8], the significant direct effect of the COVID-19 pandemic on food systems is the impact on income and the direct association with purchasing power and the detrimental access to food because of this factor. Scholars also identified that lockdown and mobility restriction measures increased households' food insecurity [49]. Structural vulnerabilities of the food systems became more apparent as the crisis evolved, aspects such as the current impact of agri-food systems on the environment and the impact of climate change, the heavy reliance on external or distant resources, inequity of access to resources, the weak governance and low institutional capacity and, the reduced adaptive capacity to cope against shocks [21, 36]. The pandemic also exacerbated food systems inequalities, increasing malnutrition and accessibility to fresh and nutritious food decreasing the quality of diets; in addition, it created supply and demand shocks, behavioural shifts in terms of how and what type of food was consumed [15, 22, 53].

The surge of social food initiatives supports the counteraction of the challenges mentioned above; specifically, grassroots food initiatives which are characterized by processes that seek to decentralize, democratize, and enable autonomous and subsidiary food systems, promote healthy food consumption, play the role of community empowerment agents, by promoting entrepreneurship and skills developments for adults and children [1,18]. Examples of grassroots food initiatives include farmer's markets, CSA, community gardens, and urban farms [19, 23]. Moreover, these food initiatives are networks, producers, consumers, and other actors that embody alternatives to the existing conventional food systems by intervening in food production and marketing in a more sustainable, economically viable, ecologically sound, and socially just way [1, 7, 17, 41]. In the wake of the COVID-19 pandemic, there was a surge of grassroots food initiatives all over the globe; self-organized initiatives were formed in Naples, Italy, to support food provisioning in urban-rural territories [16], food responses amidst the crisis included the reorganization and implementation of new strategies of already existing initiatives such as the delivery boxes, and meals of community-supported agriculture and, pop-up distribution among others [5]; in addition, informal networks strengthened the resilience of food chains, such as the case of Peru, where innovations coming from informal channels included customized food delivery using digital tools, decentralized food-selling, and clustering of product delivery [56]. Through an exploratory approach, this paper aims to understand better how grassroots food initiatives implemented innovative strategies to cope with the triggered impacts of the COVID-19 pandemic in the Cologne-Bonn region, Germany, and enhance changes towards more resilient and sustainable food production and consumption.

THEORETICAL BACKGROUND

The local grassroots food initiatives mentioned in the previous chapter belong, among other things, to the so-called social innovations. Therefore, it makes sense to deal with the definition of social innovations. Social innovation is a process that delivers new ideas and solutions that meet a social need, enhancing societies' capabilities for improved use of resources [3, 55]. These ideas and solutions can range from products, services, models, markets, and initiatives, creating new collaborative forms of social relations [4, 55, 31].

Social innovations happen both bottom-up and top-down, there are context-specific and are active at the macro, meso, and micro-level [28]. These innovations emerging from grassroots food initiatives are responses to the current agri-food system; food is a catalyst for enabling societal changes; according to [32], local food programs enable local actors to build capacities and develop social agency. Seed saving and exchange are examples of how social innovation occurs within this context; these practices facilitate new knowledge by providing platforms on agroecological management and seed collection, keeping the cultural and local context of different seed varieties; these initiatives also promote new ways of organizing, by building trust-based platforms among those involved [6]. Local food initiatives participating in regional cluster markets enable those engaged in establishing partnerships among vendors, markets managers, and customers that encourage social learning and collaboration [17].

Grassroots innovations can be defined as: “...networks of activists and organizations generating novel bottom-up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved. In contrast to mainstream business greening, grassroots initiatives operate in civil society arenas and involve committed activists experimenting with social innovations as well as using greener technologies...” [51]. In this sense, these grassroots initiatives facilitate the mainstreaming and adoption of the innovations creating niches for alternative systems that respond to a specific community need [12].

Having outlined the role of grassroots initiatives as niches for innovation is important to notice that urban food-related initiatives are particularly dynamic and constantly express the need to achieve alternative agri-food networks and models which consider community development, social equity, and solidarity [27].

Niche-based approaches to analyzing grassroots innovation focus on social networks, learning processes, and actors and resources in the initiatives [48]. Niches are considered spaces that enable the development of social and cultural expressions to sustain collective action; these theoretical spaces are formed from lessons learned by the grassroots initiatives and are shaped in a way that can be transferable and applicable in the local context [48, 50, 54].

MATERIALS AND METHODS

The analysis of the grassroots food initiatives in the Cologne-Bonn region during the COVID-19 pandemic was done using a qualitative methodology-guided data collection and analysis.

Desktop research and exploratory analysis

A qualitative approach was applied through literature review and an online survey to explore the dimensions of social innovation of each initiative and the ways that they responded to the health crisis.

Literature review

The COVID-19 pandemic and its impact on various vital sectors such as food, energy, and mobility were of great scientific interest. Therefore, relevant literature sources were researched for the paper. The literature search for this paper was carried out using platforms: Scopus, Web of Science, Google Scholar, Researchgate, as well as recent scientific contributions in the community Food for Cities (<https://dgroups.org/fao/food-for-cities>).

Online survey

Participants were recruited through a self-selection sampling method, which allows the researchers to target subjects for their specific attributes to mirror the sample closer to the studied population [2, 20]. Participation invitations for an asynchronous online survey were posted in targeted groups of active grassroots food initiatives, email addresses from websites, and contact details in channels such as Facebook and Instagram.

Online survey tools are an accessible and cost-effective approach to conduct research that promotes a user-centered model of creation and flow of information, using different channels such as social media, Email, blogs [13]; these tools also allow easier access to subjects and enable the direct transfer of responses to a database [2].

The survey's instrument was developed using the survey administration software Google Forms; content included multiple-choice, open-ended questions and Likert scale ranking options. The survey contained fifteen items and consent of participation and data usage. Items were divided into three sections: main motivations and purposes of the alternative food initiative, the experienced challenges during the COVID-19 pandemic, and the strategies to cope with the COVID-19 pandemic impacts; we conducted a thematic analysis using the survey information.

Grassroots food initiatives analysis

The analytical framework of this study is based on the niche framework proposed by [48], including the element of innovation in the context of the COVID-19 pandemic. The authors recognize the following characteristics of grassroots innovations:

1. Context
2. Driving force
3. Niche
4. Organizational form
5. Resource base
6. Innovative character for the current context (COVID-19 pandemic)

In the selected analytical framework, grassroots innovations are characterized processes not typical of a market-based economy; in the context of food initiatives, it builds on the principles of alternatives to the dominant economic system, social equity and justice, cooperation, and environmental sustainability [43]. Opposite to the Schumpeterian profit-seeking and entrepreneurial investments, the main driving forces of grassroots innovation surge from ideological commitment [46]. Food-related initiatives are influenced by the premises of social justice, reciprocity, solidarity, healthy, culturally appropriate, and sustainably grown food [26, 44]. Grassroots innovations can be organized in diverse structures encompassing cooperatives, voluntary associations, social enterprises, and informal community groups, depending on a resource base of grant funding, limited commercial activity, voluntary input, and mutual exchanges [29, 48]. The innovations adopted during the first year of the pandemic by the grassroots initiatives are described as the bottom-up solutions that responded to the local interests and values of the region and created a space for the development of skills, capacity, and resilience towards the impacts of the pandemic [45].

RESULTS

COVID-19 impact on Germany's urban food consumption

The pandemic induced several changes in how food is perceived and consumed; in Germany, consumers opted for products that observed regional and organic animal welfare standards. Compliance with social standards, biodiversity conservation, and climate protection were significant reasons to demand these food products [10]. Consumers also reported an increase in the use of food delivery such as ready meals and groceries; in this sense, there was a slight increase in online grocery shopping in the country [11,14]. In the wake of the pandemic, there was also an increase in the appreciation of agriculture; 39% of the respondents of a survey from the German Federal Ministry for Agriculture and Food reported that agriculture became more important to them during the health crisis. Additionally, preferences for local and regional food products remained an important factor for consumption (82%), particularly for fresh fruit and vegetables and eggs. In addition, regional products were bought more often during 2020 by 15% [10, 14].

Specific impacts of the pandemic in the German food system were related to the lack of seasonal abroad workers for harvesting due to the restrictions to enter the country and the significant impact on slaughterhouses, where working conditions enabled a rapid spread of infections, resulting in the closure of these establishments for specific periods [33, 37]. Responses to these challenges were the development of new machinery for harvesting and digital solutions, such as enhancing online direct distribution links between farmers and consumers [9].

Grassroots food initiatives in the Cologne-Bonn region during the COVID-19 pandemic

The Cologne-Bonn Region is a metropolitan area in the North Rhine-Westphalia (NRW), Germany; it comprises the large cities of Cologne, Bonn and Leverkusen and the districts of Rhein-Sieg-Kreis, Rhein-Erft-Kreis, Rhein-Kreis Neuss, Oberbergischer Kreis and Rheinisch-Bergischer Kreis with a population of approximately 3.6 million inhabitants. The region has solid economic representativeness in automotive and mechanical engineering, chemistry, finance and insurance, information technology and telecommunications, logistics and radio, and television [40].

Grassroots food initiatives in Cologne-Bonn involve a diverse set of practices and objectives, such as creating shorter value chains and novel relationships between producers and consumers. According to the survey results, these initiatives faced a series of challenges during the COVID-19 pandemic, which impeded rapid strategic responses such as the adoption of new delivery models, implementation of E-commerce, the establishment of new partnerships with food and non-food initiatives; a detailed description of the selected grassroots initiatives is presented in the next section. Most of the responses focused on entrepreneurial activities and, in one case, educational outreach to remain viable but also to scale-up activities.

The initiatives reported similar ideological motivations, following the principles of fairness, access to healthier, fresh, and affordable foods, but also moved by convictions on environmental and biodiversity protection assumed themselves as active entities to support society in a variety of ways, promoting social mobilization and innovation [43].

The main restrictions to continue operations during the pandemic were attributed to the lockdown measures and the constant logistic changes they needed to carry out on short notice, was also reported a decrease in the hand labor and volunteers as well as the reduction in social networking, and the reduction of sales volume. Implemented hygiene concepts and the conduction of operations through digital channels lead to higher investments. By contrast, some initiatives enjoyed a significant rise in the consumer demand for regional products; in fact, two initiatives surged during the pandemic (food delivery startups). Whereas the pandemic was still striking the globe, participants reported the plans to continue scaling up their operations.

Through our analysis, we can identify two types of benefits potential from the grassroots food initiatives: intrinsic and diffusion benefits, which according to with [32, 48], intrinsic benefits are those which have direct impacts on the community, addressing local-level issues, while the diffusion benefits are those coming from the ideological perspective, raising of awareness and the development of capacities. Organizational forms of the grassroots food initiatives are diverse, in cooperatives, civil society organizations, and voluntary groups, which support themselves through the income of commercial activities, mutual exchanges, and voluntary donations.

Table 1 presents a summary of the analysed grassroots food initiatives in the Cologne-Bonn region; overall, all initiatives are embedded in economic activities with social objectives and are stimulated by similar societal needs and principles of social justice and sustainable development, which, according to [25], are preconditions to transfer and transform collective systems visions.

Description of grassroots food initiative types

Marktschwärmer

“Marktschwärmer” (original *La ruche qui dit oui!*, in English “Food Assembly”) is a mixture of online shop and farmers’ market. Marktschwärmer aims to bring regionally produced products directly from producers to consumers. Marktschwärmer is active throughout Europe (ca. 1,400 local food assemblies), and the website is organized uniformly. Marktschwärmer “seeks to foster local food networks by connecting small local producers and buyers through a combination of an online platform with face-to-face pop-up farmers’ markets (in Germany called “Schwärmereien”)” [42]. The personal dialogue between producers and consumers is supplemented with targeted customer contact, product targeted customer approach, and product communication. With its origin in France, the startup started in Germany in 2014. The model actively embraces entrepreneurship and technology and is growth oriented. Producers and local food manufacturers pay a service charge to the two intermediaries: 8.35% to the local host and 10% to the central online platform—the customer orders products from various producers and food artisans the online shop respective Marktschwärmerie. The so-called sale is opened by the local host (the name of the food assembly operator) weekly until the distribution day. The distribution takes place in the premises of the respective food assembly (a church community or neighbourhood management), and all providers are physically present on site. The customer does not commit to a regular purchase; it is not a subscription. Marktschwärmerieien is stocked differently; producers and food artisans also offer different goods from order to order. The goods are seasonal, regional (from within a maximum radius of 150km) and processed locally.

Table 1. Characteristics of grassroots food initiatives in the Cologne-Bonn region.

| Initiative | Context | Driving force | Organizational form | Resource base | Grassroot innovation during the pandemic |
|--|--|--|---------------------------------------|---------------------------------|--|
| Marktschwärmer | Social economy (Food assembly) | Support society and the environment, improve access to healthier food | Civil society organization | Income from commercial activity | Delivery models (e.g., produce boxes) |
| Community-supported agriculture | Social economy (Community-based cooperative) | Support society and the environment, improve access to healthier food, social networking | Food cooperative | Mutual exchanges | Pick-up service organized |
| Farmers’ evening markets | Predominantly social economy (Local food access) | Support society and the environment, improve access to healthier food, social networking | Autonomous organized farmer’s group’s | Income from commercial activity | Online store opened, pick-up service organized, delivery models (e.g., delivery boxes). partnerships with non-food initiatives (e.g., IT companies or app development) partnerships with food initiatives (e.g., gastronomic sector) |

| | | | | | |
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| Food delivery start-up | Predominantly social economy (Local and organic food access) | Reduction of food and resource waste, support society and the environment, improve access to healthier food | Civil society organization | Income from commercial activity | Online store open, delivery models (e.g., delivery boxes). |
| Nutrition theater | Social economy (Community based group) | Support society and the environment | Voluntary association | Voluntary funding | New formats and new content adjusted to the new reality. |
| Direct marketing of agricultural products | Predominantly social economy (Local food access) | Support society and the environment, improve access to healthier food | Informal producer group | Income from commercial activity | Pick-up service organized, delivery models (e.g., delivery boxes) |

Adapted from (Seyfang and Smith, 2007).

Community-supported Agriculture

Community Supported Agriculture (CSA, in German – Solidarische Landwirtschaft, SoLaWi) is community-based cooperation with consumers. The members of CSA agree to provide direct and upfront support for farmers who will produce their vegetables. The farmers agree to provide a sufficient quantity and quality of food to meet the needs and expectations of the consumers [34]. The working principle is community-democratic; arrangements vary from farm to farm, from SoLaWi to SoLaWi [30]. The principle of CSA is to create a social alternative to the existing economic order. Members should decide how much money and time they want to contribute to the initiative. Yields and risks must be borne jointly, and consumers and producers must create cooperation. The CSA concept involves a monthly payment to the women producers from the members.

The members commit to pay a monthly amount fixed at the beginning of the vegetation season (February-beginning March) for one year. This amount is determined individually by the members. A guideline value is used for orientation, which is determined by the calculated budget of the farm divided by the number of members. In anonymous bidding round, each member can then decide how much he/she is willing to pay for the vegetable share. The bidding round is then repeated until the calculated budget is covered. In return for the monthly payment, members receive a weekly vegetable share, delivered to various pick-up stations (depots) in the area. Members can also get involved through participatory activities and working groups. Community-supported or ‘shared’ agriculture represents an element in the LFS spectrum where notions of community and place are positioned nearby [23].

Farmers’ evening markets

The evenings’ or after-work farmers’ market occurs after traditional working hours. Exhibitors present themselves on the market grounds with a variety of offers. Vegetables, cheese, bread, eggs, sausage, honey, and much more are offered for sale by producers and processors from the region. The after-work markets fulfil wishes for shopping quickly after work, but without stress and long queues at the checkout of many, especially young, working people. Many German cities realize that the traditional weekly market no longer appeals to parents, students, or young, working people, as the stalls often close around noon. The unique feature of after-work markets is the sale of the goods in the market stalls from regional producers themselves. It is instead a rarity at the traditional weekly markets in Germany. Often after-work markets are organized as an association; the vendors are members of the association themselves and can thus influence the development of the after-work market. Often benches and seat cushions are set up at evening markets to linger and enjoy. A bit of funfair flair comes with the friendly supporting program. Shopping becomes an excursion. The residents initiate the after-work markets, which often organize themselves into an association to look for market vendors. The evening markets contribute to the development of the neighbourhood - “a meeting place (and news exchange) for people from the city quarter.”

Food delivery start-ups

The COVID-19 has boosted online food delivery (OFD) products and services [24]. The new constraints led firms around the globe to innovate, scaling up the digitalization of food supply chains [39]. This widespread adoption of e-commerce by large and small retailers and food service (restaurant) enterprises served an essential role in ensuring food access to consumers [39]. The study area is no exception either. The boxes business flourished there, and at least two new online delivery services were

established during the pandemic time in the researched region: Himmel und Äad (<https://www.himmel-un-aad.de/>) as well as Frischepost (<https://koeln.frischepost.de/>). While German Startup Frischepost has only opened a new branch in Cologne, Himmel und Aed is an entirely new e-cargo bikes food delivery company in the Cologne-Bonn region, established in 2019 as a student initiative financially supported by Regionalwert AG Rheinland (<https://www.regionalwert-rheinland.de/>). Both delivery services are connected to the region but have different philosophies. Frischepost products come from within a 100-kilometer radius of Cologne. Customers can order a wide assortment of food and other products: breakfast boxes, seasonal fruit and vegetable boxes, milk, eggs, sausage, cheese, meat, honey, pasta, spreads, drinks, as well as drugstore stuff from small manufacturers. A cookbook author creates the recipes for the cooking box, especially for Frischepost. In any case, this food network is perfect for all local patriots who like to get to know local products. Himmel und Äad brings food produced and processed from organic farms and small organic food manufacturers of the Cologne-Bonn region. The young team focuses on short distances and sustainable agriculture, honesty, transparency, and cooperation with all stakeholders. In this way, they avoid unnecessary CO2 emissions, protect groundwater and natural biodiversity, and strengthen regional structures in agriculture and food production. Customers can order a wide assortment of food and other products as a box: fruits and vegetables, bakery products, dairy products, and eggs, ready-made food such as soups and salads, meat and sausage, dry products such as pasta and flour, spreads, spices and oils, beverages, non-food such as vouchers, seasonal calendars. Both systems work without yearly subscriptions.

Nutrition theatre

The Gorilla Nutrition Theater is a Cologne initiative, consisting of actors, theatre educators, and directors, founded in 2015. The Gorilla in the namesake stands for the strength and courage to eat a balanced diet. Since its establishment, theatre programs for different target groups have been developed and presented thoroughly and passionately. The central themes of theatre's work are connections between nutrition, health, and the environment openly and playfully through art and experiential educational approaches. Together with educators, teachers, and parents, actors help enable children to reflect on and understand the impact of their actions on the world and themselves, and to be able to make responsible, sustainable decisions - for themselves as individuals and for the society in which they live and of which they are apart. The global impact of personal actions works as a perspective and dimension into theatre education programs. The performances occur in schools, kindergartens, or other child and youth care places. During the performances, classrooms/group rooms are transformed into a small theatre. The theatrical programs bring variety into the children's everyday life and enable cultural participation. Since 2018 the theatre collective leased an area of arable land to cultivate food (for the first time in its life!). In theatre plays, actors convey facts from science and research entertaining and low threshold. In a holistic form of presentation and communication, the theatrical plays aim to appeal to the senses of children, young people, and adults - whether with or without special needs, with or without disabilities - and to arouse interest and provide impulses and stimuli for their lives. The theatre collective considers in their plays the current state of knowledge of research on nutrition and health and their ecological, economic, social, political, and cultural aspects and interactions. From this arises the claim to educate and train actors themselves constantly.

Direct marketing

In the pandemic, interest in direct marketing became much more substantial from both the supply and demand sides. This does not only mean popular models such as sales, e.g., direct from the market, delivery boxes, and crowdbutchering models. Market vendors were partly and sometimes heavily restricted by the pandemic rules (total lockdown, closure, or reduced implementation of weekly markets). Especially market vendors, who get their products from local farmers, develop, and implement new concepts, like direct marketing of fruit and vegetable baskets in different sizes. In the COVID-19 pandemic, a new network of regional organic farmers was built, and seasonal organic quality produce reached its new customers.

CONCLUSION

The COVID-19 pandemic brought stronger attention to the existing challenges in the current urban food systems. As a result, structural problems were exacerbated while new challenges were born. Overall, this exploratory study of the responses of grassroots food initiatives in the Cologne-Bonn region sets a base for deeper analysis of the innovation process dynamics and the scaling-up from the food initiatives themselves and the innovations.

Models such as the Community-Supported Agriculture and the farmers' markets with a direct producer-consumer relationship offer the opportunity to bring urban citizens closer to the current food system, especially during crises, such as the COVID-19 pandemic [35].

Local supply lines, where local demand is supplied through different initiatives and innovations such as the ones presented in this study, that integrate agrobiodiversity and social justice principles, for example, might contribute to shaping more resilient urban food systems, delivering immediate solutions [38, 56]. Furthermore, the surge of new food and non-food partnerships in the local food supply chains secures the stability of the systems among the supply chain partners [52].

Finally, grassroots food initiatives' significance relies not only on food provision but also on the development of new partnerships producer-consumer, the right to access fresh and healthy food, the promotion of social engagement, empowerment, and education. All this contributes to change, to a food system transformation.

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ECOLOGICAL URBANISM AS A CONDITION FOR URBAN LIFE FOR INTERNALLY DISPLACED PEOPLES

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ABSTRACT

This paper uses the concepts of sustainability and habitability to define and measure Ecological Urbanism in informal settlements founded by people forcibly displaced by violence. The objective is to identify the obstacles to meeting the tenants of Ecological Urbanism in informal settlements. We offer primary research from La Primavera, an informal settlement founded by internally displaced people in the late 1970s, located in the *Corregimiento* El Hatillo of Barbosa, Antioquia in northwestern Colombia. Primary research includes qualitative and quantitative data gathered through 72 surveys and technical assessments of properties and houses in the settlement. Situated between the Aburrá River and the northbound highway, above a gas pipeline and under an electricity pylon, La Primavera exists in a state of extreme risk, exacerbated by increasing migration which threatens to exceed the carrying capacity of the territory. Moreover, in Article 35 of Law 388 of 1997, the territory was declared a protected or restricted area and earmarked for the development of the regional commuter train, called the *Tren de Cercanías*, in 2017. The case study highlights the ambiguities of the development agenda in Colombia by showing how development projects designed for the economic betterment and environmental conservation of the region negatively impact the quality of life for the most vulnerable inhabitants and expose them to greater environmental, economic, and social risk.

KEYWORDS

Ecological Urbanism, Sustainability, Habitability, Sustainable Construction, Internally Displaced People, Colombia

INTRODUCTION

For decades, Colombia has been characterized by high levels of rural-urban migration as refugees flee the violence of the Armed Conflict and the limited opportunity available in rural regions. Migration patterns have resulted in the proliferation of informal settlements as displaced individuals and economic migrants often do not have the resources needed to pay for food and accommodation within existing city limits. Therefore, they settle in the outskirts of cities, building homes from the materials available, oftentimes taken from landfills, forming neighborhoods that are only sometimes consolidated and incorporated into the city they adjoin.

One such informal settlement is La Primavera. Located in the Municipality of Barbosa, in northwestern Colombia, approximately 42km north of Medellín, the main urban center of the Metropolitan Area of the Aburrá Valley and the capital city of the Department of Antioquia. La Primavera is a peri-urban settlement situated in the *corregimiento* of El Hatillo along the northern bank of the Aburrá River. Figure 1 shows a map of La Primavera. The top left of the map delineates the boundaries of the Municipality of Barbosa, and the bottom left highlights the location of the settlement within the municipality. The right side of the map shows the distribution of the settlement along the riverbank, with the altitude of each segment marked, high altitude on the left and low altitude on the right.

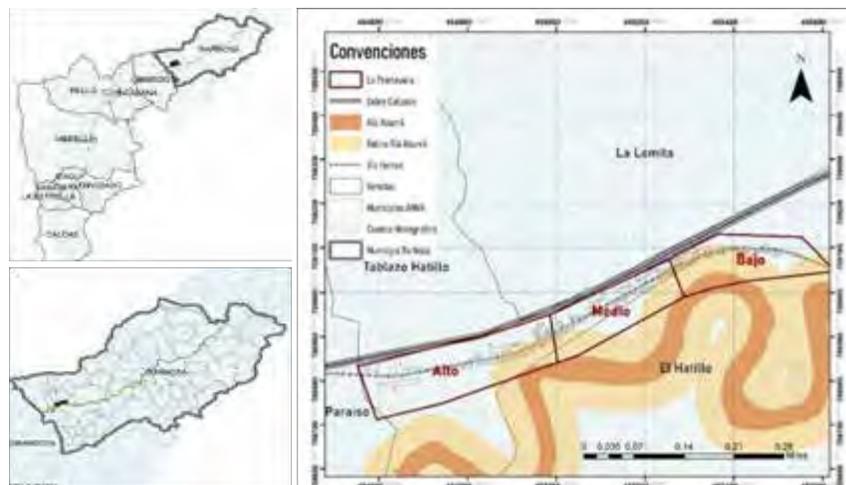


Figure 1. Map of the La Primavera Settlement in the Municipality of Barbosa.

The lands on which La Primavera is settled have been declared a protected or restricted area under Article 35 of Law 388 of 1997. Under said law, lands can be declared protected areas or non-intervention areas due to their geographic, landscape or environmental characteristics, can be earmarked as zones for infrastructure or public utility development, or can be declared restricted due to high, non-mitigable risk to human settlement [1]. No matter the specific class of the area, housing development and urbanization is severely limited or outright prohibited. In La Primavera, the territory is declared protected because it meets all three conditions of the law. The settlement extends all the way down to the riverbank, which is considered an at-risk natural habitat and the protection of the waters of the Aburrá River is of grave concern to local and national conservation efforts alike. Furthermore, there has been substantial development and intervention in the landscape for the provision of public utilities, and La Primavera is situated above a gas pipeline, under an electricity pylon, and alongside the northbound highway and the historic train tracks. Finally, the combination of natural landscape features and public infrastructure interventions means the area is substantially affected by flooding and landslides, both of which are non-mitigable risks that put human settlers in danger.

Thus, the settlement is in a state of existential crisis: the social situation caused first by the Armed Conflict, then by the drug trade, and most recently by internal urban displacement has pushed people to the area for decades, while the built and natural environmental conditions make it an untenable place to live. However, to understand why La Primavera was situated in its current location despite the protected or restricted legal status of the land, it must be understood that the settlement was founded in 1978, long before Law 388 was passed, by people forcibly displaced from the Chocó and Urubá regions of Antioquia by the Armed Conflict [2].

The settlement's history can be divided into four periods. The first period spans from the settlement's founding in the late 1960s and 1970s until 2001. During this time, the territory was populated with a growing number of refugees, and the settlement expanded downwards towards the river. In 2001, the settlement was massacred [2]. The second period of La Primavera's history, which lasted from 2002 to 2013, can be considered the period of consolidation. In 2013, residents created the Association of Victims and Displaced Persons *Los Meadros Nuevo Amanecer* [2].

Growth is the defining characteristic of La Primavera's third historical period which stretched from 2013 to 2018 [2]. In 2016, the Department of Antioquia in conjunction with the Municipal Government of Medellín and the Metropolitan Area of the Aburrá Valley announced that construction of the local commuter train to connect all 11 municipalities in the 83km-long valley would begin upon the completion of the feasibility assessments scheduled for 2017 [3]. The promise of stable employment and economic growth brought new waves of migrants from rural regions and the peripheries of larger cities in the Metropolitan Area [2], where insecurity and impoverishment are high, and residents fear urban organized crime and other illegal armed actors.

The last study of the settlement was conducted in 2015 by Corporación Región in partnership with the University of Antioquia, financed by the Iglesia Católica Alemana Misereor, a local NGO, when the inhabitants in the settlement totaled 570 people [2]. Of these, 392 were individuals forcibly displaced and legally registered as Victims of the Armed Conflict in the *Registro Unico de Victimias* (The National Registry of Victims). Almost half, 49.6%, of the families resettled in La Primavera were displaced from other municipalities in the Department of Antioquia, including Anorí, El Bagre, La Pintada, Ituango, San Jerónimo, Itango- Vereda El Aro, Segovia, Taraza, Cereté. The rest of the population was comprised of second and third generation of inhabitants, children or grandchildren of the displaced population, as well as newly arrived migrants who are not considered part of the legal category of Victim. The second largest percentage of the population, for instance, is comprised of people forcibly displaced from the cities of the Metropolitan Area of the Aburrá Valley (Bello, Barbosa, Itagüí, and neighborhoods in Medellín like o Zamora, Santo Domingo and La Comuna 13), but who do not fall into the legal category of Victim of the Armed Conflict. In many cases, many of these people came to live in La Primavera after other processes of displacement. Only 4.3% of the population comes from other departments in the country [3].

Data regarding length of residency confirms the settlement pattern. Individuals recognized as Victims in the 2015 census had an average of 18.3 years of residency in La Primavera, in contrast with those classified as economic migrants or urban refugees, who had on average less than 8 years of residency in the settlement [2].

The last period in La Primavera's history spans from 2018 until the present day. From the 83 residences recorded in 2015, the settlement grew to 168 residences by 2018, and continues growing at unprecedented rates [2]. Recently, internal urban displacement has become an important dynamic in the Municipality of Barbosa. Moreover, the city has received ever growing numbers of international refugees fleeing the economic collapse in Venezuela. The promise of affordable housing has drawn many of these newly arrived migrants to La Primavera and other similar settlements [2]. Tensions between the different population groups have increased due to competition for resources and the absence of the State in the territory. Tensions have only grown as different bands of armed actors have stepped in to take the role of absent State [2]. Furthermore, the rapid increase in settlement along the riverbank and the exploitation of the river's resources have undermined the stability of the land along the river's edge, causing erosion that eats away at the foundations of many of the settlement's residences [2]. In short, the unprecedented population growth has increased both the social and the environmental risk experienced by residents, leading to new concerns regarding sustainability and the long-term viability of the settlement, and raised the possibility of relocation as a matter of necessity.

Nonetheless, the questions of social and ecological instability are not the only causes for concern. Recent plans for the local commuter train, a project that promised to bring economic prosperity to the region and drew people to the settlement, have been published, and planners have announced their intention to reuse the pre-existing train tracks as the basis for the new transport infrastructure [4]. For residents of La Primavera, that means the new train will go right through the middle of their homes, requiring that they move before construction begins. At the moment, it is unclear if the State will offer assistance in relocating residents or buy their houses at market value. Furthermore, as the settlement is still informal, the market value of the homes that will be destroyed for the project is undetermined.

La Primavera is not the only informal settlement facing an uncertain future. The sad fact is that there is no formal process to regulate the consolidation and incorporation of informal settlements, nor the treatment of the rural-urban migrants who live in such places. For decades, urban and regional planning in Colombia has been characterized by the absence of directives to guide territorial settlement and establish requirements for settlements. Only in 2015 did the Colombian National Government adopt Objective 11 of United Nation's 2030 Agenda for Sustainable Development "Sustainable Cities and Communities" into

regional planning, requiring that planners and developers include environmental determinants as a primary criterion for the development of a territory for human settlement. The adoption of Objective 11 means that urban and regional planners must attend to the environmental problems that result from informal settlements as well as establishing a basic quality of life for rural-urban migrants in these settlements. Nonetheless, planners lack theoretical and practical instruments to evaluate quality of life in and the sustainability of new settlements.

Therefore, objective of this paper is to identify the obstacles to ecological urbanism, read from the perspective of habitability, in informal settlements founded by people forcibly displaced by violence and conflict. We ground the discussion in the case study of La Primavera in Barbosa, Colombia. We begin by exploring the theoretical background of the study, defining habitability and sustainability as two necessary elements of ecological urbanism. We then suggest that sustainable construction is the way in which these concepts are physicalized in architecture and urban design. Using the criteria set in the discussion of sustainable construction, we evaluate the results from the case study of La Primavera. We close with a holistic analysis of the development agenda in Colombia and of where informal settlements like La Primavera fall in this agenda.

ECOLOGICAL URBANISM: THE CONJUNCTION BETWEEN HABITABILITY AND SUSTAINABILITY

Ecological Urbanism: Reconceiving the city as an ecosystem

“[Cities] consume energy in their operation and in the extraction and preparation of materials, and they generate waste and pollution,” [5] argued Egyptian architect Rabee M. Reffat in the *First International Architecture Conference* of Cairo University in 2004. In short, cities are like living organisms; they have “metabolism” [6] in that they consume resources and produce waste. Thus, like all other organisms, cities are part of a larger system, an ecosystem, and can only survive if their surrounding ecosystems do as well.

The concept of understanding cities as organisms and therefore designing them in balance with the natural environment was first proposed by architect and planner Miguel Ruano who introduced the concept of “EcoUrbanism,” or “the development of multi-dimensional sustainable human communities within harmonious and balanced built environments” to scholars in 1998 [7]. In the early 21st century, the concept underwent a period of discussion and consolidation, finally becoming known as “Ecological Urbanism” in 2007. Susan Hagan, in an essay for *The Architectural Review*, explains:

The goal of Ecological Urbanism is to create ‘artificial ecosystem’ cities that achieve the same interdependent efficiencies and life-preserving redundancies as natural ecosystems, turning the current linear pattern of energy-in-one-end/wastes-out-the-other into a loop: wastes become energy. The emphasis on environmental systems is a very different way of thinking about the city: urban sites are seen as locations of, not only demand for but supply of, resources. It is an engineering model, vitally important [6].

Thus, ecological urbanism forces us to reimagine the way in which we understand cities. The environmental degradation seen over the course of human history has taught us that we cannot think of cities as the physical manifestation of the triumph of human culture over nature; in doing so, we create false dichotomies between the built and natural environment that spells destruction for both. For cities to become places that guarantee human survival over extended periods of time, the built environment cannot subsume or obliterate the natural environment, but must be in balance, using resources at a rate that allows us to replenish them and producing waste in a way that allows it to become productive material once more [7]. Thus, ecological urbanism asks us to see building, maintaining and living in cities as processes of “adaptation rather than domination, ‘living with’ rather than ‘living over’” [6]. [7] suggests that new information technologies can help us understand and measure environmental, social, and economic realities, and that by planning for three levels of the city – aerial, on the surface of the land, and underground – we can better enact the precepts of ecological urbanism.

Yet, as [5] reminds us, “Theories about the urban condition are useless without the ability to deploy them.” Therefore, in this article, we argue that for a city to be a viable ecosystem, as suggested in the theory of Ecological Urbanism, it must be both habitable and sustainable. Habitability, as a general concept, refers to the quality of a built environment to respond to needs of its human population, while sustainability refers to the viability of a place over time due to the use of resources and the management of waste. We suggest that the precepts of sustainable construction provide apt criteria for the evaluation of habitability and sustainability, providing the means for measuring the application of Ecological Urbanism in the architecture and urban design of different settlements.

Habitability: Making cities comfortable places for people to carry out their basic activities

Douglas [8] in a 2012 editorial about Ecological Urbanism argues that “urban ecosystems are a hybrid of natural and man-made elements whose interactions are affected not only by the natural environment, but also by human culture, personal behaviour, politics, economics and social organization.” In that sense, the purpose of city to be a place for human beings to live, realize their daily activities, and feel fulfilled while doing so. Therefore, in this paper, we adopt the concept of habitability to analyze the way in which the built environment responds to and satisfies the needs of human residents, arguing that habitability is the first element needed for a city to be understood as an ecosystem.

The concept of habitability is primarily used in countries like Spain and Colombia for establishing legal regulations and norms regarding construction practices, despite its origins in sociology and social psychology [7, 9]. In governmental regulatory application, the concept of habitability is most often used to analyze the interior of a residence or commercial space, the materials used in the construction, and the use of resources within the building.

Nonetheless, scholars like [10] and [11] have come to believe that an interior-centered definition of habitability is incomplete and have therefore refined the concept by dividing it two: internal habitability, which refers to the architectural conditions of buildings as individual units, and external habitability, which considers the way buildings are integrated into the built and natural environments that surround them.

As external habitability evaluates the interconnectivity between residence and built environment—i.e. neighborhood, commercial areas [12], urban infrastructures and installations [13]—it permits a deeper analysis that incorporates the study of how these spaces are used by city residents. For example, [14] argues that habitability necessarily implicates the relationship between human beings and space. [11, 12 and 15] build upon that foundation, considering habitability as the capacity of built spaces to satisfy the physical and emotional needs of the individuals and groups that occupy them. Moreover, according to [16], shifting the discussion of habitability from its internal to its external dimension enables the concept to “face social and environmental issues” in a way that allows cities to be understood as “systems of structures and actions” that balance “the satisfaction of social needs and the regulation of the use of environmental resources” to “stimulate strategies for transformation” [16]. External Habitability gives us the tools to understand the city as a dynamic system that feeds upon itself.

Sustainability: Making cities viable over time

The second element of Ecological Urbanism is sustainability, or the ability of a place to survive and thrive over time. Current understanding of sustainable cities is based on the 1987 definition of sustainable development offered in the *Report of the World Commission on Environment and Development: sustainable development is that* “which meets the needs of the present without compromising the ability of future generations to meet their own needs” [17, 18, 19]. Thus, sustainability implicates balancing social, economic, and environmental considerations to provide for current and future generations in a way that assures healthy growth not only for the human population but also the natural environment [18, 20]. As such, since the 1980s, scholars have suggested that sustainable development is the “integrative and holistic process of maintaining a dynamic balance between the needs and demands of people for equity, prosperity and quality of life, and what is ecologically possible” [5, 21, 22].

The best way to realize the objective of sustainable development, we argue, is to consider the urban environment as an ecosystem as proposed in the framework of Ecological Urbanism. Thus, we can think of a city having a metabolism, which uses resources and produce waste, but also as a part of an “ecological feedback loop” [6], which will achieve homeostasis, the balance needed for long-term survival and well-being, when the consumption of resources does not exceed the ability to produce them, and the production of waste does not overwhelm the ability to transform that waste into a new resource. “In a healthy ecosystem in nature,” [6] explains, “each biotic member of the system gives as well as takes. If cities are to be physically reformed, they can no longer parasitically consume more than they produce, and architects need enough understanding of the ecosystem model to be able to help close the metabolic loop” [6] and realize sustainability.

Sustainable Construction: Making Ecological Urbanism a reality

To qualitatively and quantitatively measure the level to which a settlement fulfills the precepts of Ecological Urbanism, understood as the conjunction of habitability and sustainability, we turn to concept of sustainable construction, which applies the values of sustainable development to the construction industry for the sake of bettering the quality of life of current and future human residents in a territory [5, 17, 18, 20, 23, 24, 25, 26]. Sustainable construction argues that the careful use of resources and waste management can result in more habitable living conditions and psychological and emotional satisfaction [27].

[18] explains that “construction has a significant effect on quality of life: its outputs alter the nature, function and appearance of the towns and countryside in which people live and work. The construction, use, repair, maintenance and demolition of such infrastructure consume resources and energy and generate waste.” Because construction not only shapes the built environment on an immediate physical level, but also impacts lifeways, quality of life, and the maintenance of environmental resources in the long-term, it is an industry that must also put sustainability first to bring “environmental responsibility, social awareness, and economic profitability objectives to the fore in the built environment and facilities for the wider community” [17, 18, 26, 29, 30]. [20] further suggests that sustainable construction can be considered as “the creation and responsible management of a healthy built environment based on resource efficient and ecological principles.” It involves changing the fundamental worldviews underpinning the construction of built environments from “linear to cyclical approaches” [26].

Moreover, this change in perspective implicates understanding sustainability in construction as more than environmental responsibility and resource management, but also as a way of seeing the built environment as an essential part of the economic and social life of a community. Therefore, in 2003, [21] established a set of four criteria for determining if the built environment of a specific settlement was sustainable. The first criterium is “The physical structure; how the settlement sits within the natural environment and therefore responds to the topography; the spatial relationship between the different parts of the city; and the form of the built environment;” the second refers to “The utilization patterns which are formed by the way the settlement uses its resources and which are described by the infrastructure and services provided;” the third is “The social patterns; how people live, learn and work in, and relate to their settlement, and the opportunities provided by the settlement for meeting these social needs;” and the last is “The operational patterns; how the settlement functions and is managed” [5]. With these criteria, the concept of sustainable construction transcends environmental sustainability to embrace economic and social sustainability, emphasizing the possible value addition to the quality of life of individuals and communities.

[5] builds upon [21]’s general criteria by establishing specific criteria to meet for each aspect of sustainability: ecological, economic, and social. The criteria are shown in the table below.

Table 1: Objectives for Measuring Sustainable Construction

| SOCIAL | ECONOMIC | ENVIRONMENTAL |
|----------------------------|----------------------------|--------------------------|
| Occupant Comfort | Local Economy | Water |
| Inclusive Environments | Capital Costs | Energy |
| Access to Facilities | Ongoing Costs | Waste |
| Participation & Control | Efficiency of Use | Site |
| Education, Health & Safety | Adaptability & Flexibility | Materials and Components |

From Reffat (2004, 6).

[5]’s fifteen objectives of sustainable construction dovetail nicely onto the concepts of internal habitability, external habitability, and sustainability.

LA PRIMAVERA CASE STUDY

Methodology

This article combines qualitative and quantitative analysis to measure the extent to which the criteria of sustainable construction are met in the informal settlement of La Primavera, as a means of measuring ecological urbanism, understood as the conjunction of internal and external habitability and sustainability. It is the product of the research program “Vulnerability, resilience and risk of communities and supplying basins affected by landslides and avalanches” code 1118-852-71251, contract 80740- 492-2020 held between Fiduprevisora and the University of Medellin with resources from the National Financing Fund for Science, Technology and Innovation, Francisco José de Caldas Grant. Both the qualitative and quantitative analyses focused on occupant comfort, access to facilities, participation and control, education, health and safety, as well as adaptability and flexibility of the sites and the management of water and waste as the primary indicators in internal and external habitability and environmental sustainability.

Using the three criteria of social, economic, and environmental sustainability planted by [5] regarding sustainable construction, we evaluate two in the following study of La Primavera: social and environmental sustainability. We have chosen not to address the economic elements here because they don't play into the theoretical definition of internal and external habitability, which is the means of measurement that we have chosen to evaluate ecological urbanism.

The qualitative analysis entailed the application of a large-scale household survey consisting of 58 questions. Questions were either multiple-choice in which respondents could select one or more answers, or open-ended questions in which respondents could reply in as much detail as desired. During analysis, questions were grouped in two categories: internal habitability, which studies factors inherent to a residence like size, construction material, and public service access, and external habitability, which refers to the factors related to the built and natural environments and the social context.

In total, surveys were applied to 72 heads of household, of which 46 were women, 25 were men, and one individual did not wish to give their personal information. The age range can be divided into three basic groups: 26 respondents were between 18 and 40 years old, 33 individuals between 40 and 60, and 13 people over the age of 60. The length of residency was similarly diverse: 17 inhabitants have lived in the territory for a period of less than 5 years, 11 inhabitants from 5 to 10 years, 24 residents from 10 to 20 years, and 18 for more than 20 years. The diversity of residency is also present in the legal status of residents and their titles: 61.6% of the population state that they have legal title and another 16.7% claim to be the owner, but without legal title. Furthermore, 28 of the interviewees declared themselves as displaced (one due to flooding and another a Venezuelan migrant), 20 said they were not displaced, and 24 chose not to respond to this question.

Quantitative analysis included a schematic survey of the interior distribution of the house accompanied by a photographic record. Furthermore, quantitative data was complemented by a qualitative model for evaluating the habitability of each residence: technically trained personnel, including architects and engineers, evaluated the infrastructure conditions and environmental threat and risk for each of the selected residences in the settlement.

RESULTS AND FINDINGS

The results here presented are divided in three sections according to the concepts used to define ecological urbanism: Internal Habitability, External Habitability, and Sustainability. Each section combines qualitative and quantitative research.

Internal Habitability

To assess Internal Habitability, factors like construction materials, home size and population density in the residence, access to public services, and satisfaction with one's residence were evaluated. The primary research shows that internal habitability of residences in La Primavera is adequate, and residents are for the most part content with the living conditions inside their homes. Nonetheless, the buildings do present some grave deficiencies, particularly in terms of access to public services.

The first indicator of internal habitability is construction material; the materials used should be safe, responsive to environmental conditions, and economically accessible for residents. In La Primavera, buildings typically have one of three structures: palafitte (17%), portico (54.8%), or wooden base structure (54.8%). Some 63.9% use concrete flooring and another 23.6% use tile. Nonetheless, 11.1% of residences still have dirt floors. The quality of materials used in construction becomes more of a concern in relation to the materials used for walls and roofing. The most common material used for building walls is wood, and 37.5% of houses have wooden walls as well as frames. Brick is the second most common material, as 29.2% of houses use plastered or stuccoed brick for walls and 22.2% use exposed brick. The last 8.3% of homes have walls made from recycled or recuperated materials. The materials used for roofing are the most concerning. Some 61.6% of houses have tin roofs and 13.9% use clay roof shingles called *tejas*. However, in 18.1% of residences, asbestos, which is toxic to humans, is used for roofing. The commercialization of asbestos was banned in Colombia in June 2019 but continues to be a predominant material in construction.

The second indicator of internal habitability is house size and population density. Houses do not necessarily have to be large, but they should have enough room that all residents can carry out their daily tasks without feeling confined. Moreover, if the building is a multi-use structure, the ideal condition is that there is enough space for the different uses to remain separate. The research shows that in La Primavera, house size is not uninhabitable, but there are significant concerns in relation to overcrowding and having enough space to adapt a home for multiple functions.

Regarding residence size, the smallest spaces, corresponding to 9.7% of interview respondents, were approximately 30 square-meters. The largest spaces, corresponding to another 9.7% of the population, measured 80 square-meters. However, majority of residences occupy a space between 35 and 70 square-meters. The houses in high-altitude zones, further away from the river, are typically the largest, and generally belong to the earliest residents.

Moreover, overcrowding is not a particularly grave concern. In 83.3% of cases, a residence is occupied by a single-family group. Furthermore, family size per residence is small. The research shows that 23.6% of families are comprised of two people, 19.4% of 4 people, and 13.9% are single-person homes. Nonetheless, 12.5% of residences are inhabited by two family groups and 4.2% by three family groups. Moreover, about 24% of families have between five and seven members. For those whose homes are less than 60 square-meters, having multiple families in a single home or a family of 5 or more people presents serious conditions of overcrowding, based on Colombian norm which specifies that a family group comprised of three individuals needs a minimum area of 60 square-meters to have healthy and habitable conditions in terms of population density.

In terms of being functional multi-use spaces, the residences of La Primavera once again meet standards of adequacy, but not excellence. Approximately, 25% of families dedicate their dwelling not only to residence, but also to some productive activity (store, food service, etc.). About 14.3% use the common spaces in the house for productive or social activity during the day, but as sleeping quarters at night.

The main deficiencies in terms of internal habitability are related to access to public services. There is no access to formal services, and the population has responded by building their own informal service networks. The service with the best coverage is energy, which reaches some 97.2%. Yet, even with electricity, more than 70% of residences continues to use only or mainly natural light and ventilation. The second-best service in terms of coverage is water, which reaches 91.7% of residences. However, for many, the water that comes out of the tap is not potable. For all, the water comes from the local reservoir higher up the hillside, and not from municipal treatment plants. Gas service, to which 33.3% of the houses have access, is individually provided through personal propane tanks. There is no public infrastructure for delivering gas to residences.

The most worrying deficiencies are the absences of a sewage system and a garbage collection system that is permitted to take waste all the way to the landfill. Houses typically have a toilet (98.5%) and a shower (83.8%), but only 52.9% have a sink. Nonetheless, these facilities are not connected to the public sewage infrastructure. Residents have attempted to address the lack of state support for infrastructure development by building their own informal systems. Yet, these systems are problematic; for example, the informal sewage system collects wastewater and dumps it into the river. However, residents have not been able to build a treatment plant for the water, which results in the contamination of the river and the destruction of the surrounding ecosystem.

Furthermore, due to the lack of garbage collection, residents have created local dump sites for trash behind the settlement, but leakage from the dumpsites is carried to the settlement by rain and also contaminates the land, poisoning fields used for agriculture and animal husbandry as well as further impacting the river. As a result, residents of La Primavera are exposed to multiple sources of contamination. The community classifies the effects of the contamination caused by the lack of sewage and garbage as: bad smells (62.9%), contaminated rivers (50%), surface flow of wastewaters (40%), and the accumulation of waste (22.9%).

The final indicator of internal habitability is the perception of the suitability of the residence for one's everyday needs. The responses gathered during the primary research were contradictory. Some 58.3% of residents answered that yes, they consider that their residences meet the conditions needed to carry out their daily lives. In contrast, 41.7% believe that their houses are insufficient to meet their daily needs.

For example, in response to the question "Would you like to improve your house? If so, which space and why?" respondents most often expressed the desire to expand their homes. Many stated they wanted individual bedrooms, to renovate the kitchen, and to improve the bathrooms.

In conclusion, the findings in relation to internal habitability have shown that the duration of residency in the territory has permitted the population to consolidate the houses and better their conditions of internal habitability, in terms of architectural elements. They have established self-managed services to compensate for the lack of State supported public infrastructure. However, the remarkable initiative of residents still does not compensate for the concerning failings of the State to provide public services and formalize the territory.

External Habitability

Nonetheless, we have argued that habitability goes beyond seeing the building as an individual unit, and that to truly analyze if a home is habitable, one must understand that a house is situated in a city network. The network must be navigable and public services like education, health care must be available as well as access to places to buy food and other basic necessities and to social facilities.

In La Primavera, the internal habitability of the residences can be considered adequate; however, the external habitability of the surrounding urban system is not. There are grave failings in the provision of public facilities like parks and community centers, physical and institutional infrastructures, and meeting places.

In the primary research, 52.9% of respondents stated that there are no public facilities at all. Amongst those that do recognize public facilities, 25% stated that they do have access to an educational center even though the closest school is located on the other side of the highway, which lacks a safe means for pedestrians to cross. The same pattern is seen in relation to other public facilities; 20.6% identify a sports center, 17.6%, a cultural center, and 13.2% a health center, yet all these facilities are located outside of the settlement in the township of El Hatillo or in the urban center of Barbosa. In relation to meeting places, the most identified place was the community hall, which offers a wooden stage, but has deficiencies in floor and roofing.

In conclusion, in regard to external habitability, different from internal habitability, there were no redeeming factors. Quite simply, there is no access to infrastructure, to public services like education and health care, and social or recreational facilities were severely limited.

Environmental Risk

In the right to a dignified living space guaranteed in Article 51 of the 1991 Political Constitution of Colombia requires that the places where people live be safe for habitation and environmentally sustainable. Therefore, Law 338 of 1997 was allowed to declare certain lands restricted because the level of non-mitigable environmental risk was too high for safe settlement or because human occupation exceeds the carrying capacity of the territory.

In La Primavera, the level of non-mitigable environmental risk is problematic. Of the 72 homes studied, 21 were found to be located in flood zones subject to high levels of risk. While the technical assessment only found 21 families to be in the high-risk category, 26 of the respondents felt that their home and safety was severely at risk due to flooding.

While the risk of flooding is well-known throughout the settlement, there are other environmental threats that put the population at greater risk but are less noticed. For example, erosion of the riverbanks from under house foundations is a major problem. In the technical assessment, 63 of the 72 houses studied were found to be in medium and high-risk zones. Nonetheless, 42 of the respondents said that erosion was not a problem and risk was minimal.

The same pattern was seen in relation to landslides. While 45 of the respondents answered that the threat of landslides is minimal, only 13 families live in a low-risk zone. All the other houses evaluated were located in areas subject to high or medium levels of threat from landslides.

Figure 2 offers a map of the levels of risk for houses in the settlement. Houses with low environmental risk levels are marked in green, medium risk yellow, and high risk with red. The map highlights that the houses in the highlands of the settlement have lower environmental risk, as well as having higher conditions of internal habitability. In contrast, risk is concentrated in the lowlands of the settlement, where people have been settled for less time and the conditions of internal habitability are generally lower. The map emphasizes the correlation between risk and habitability.

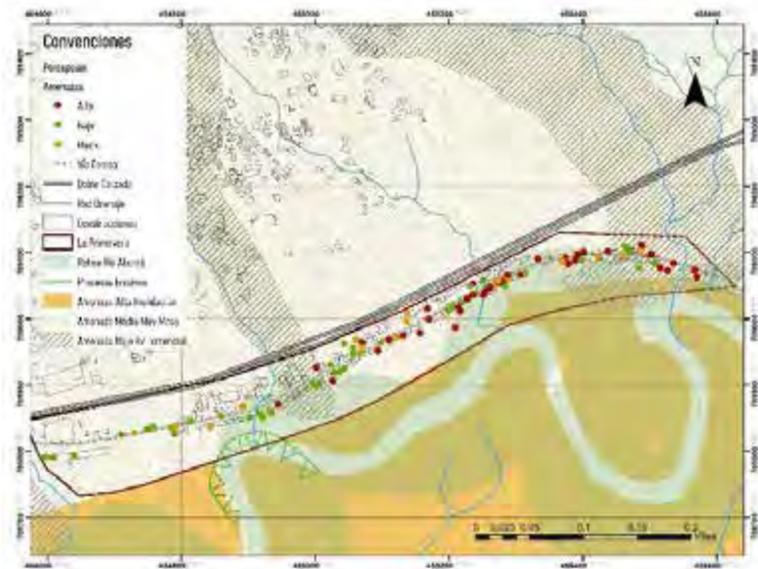


Figure 2. Map of the level of environmental risk in La Primavera.

If the analysis of External Habitability shows great deficiencies in meeting the standards of ecological urbanism, then the findings regarding Environmental Risk demonstrate the impossibility of speaking of Ecological Urbanism in informal settlements. The most accessible areas of settlements, like La Primavera, are often those most at risk from natural threats.

CONCLUSION

In this article, we have analyzed the concept of ecological urbanism, which refers to understanding cities as ecosystems in which resources are consumed by the beings that inhabit them, and waste is produced. We have argued that for these systems to be viable over time, the consumption of resources cannot exceed the capacity of the system to provide them, and that waste must be managed so that it can be converted once again into a resource or disposed of in a way that minimizes harm. Furthermore, we have suggested that the purpose for cities is to provide homes for human inhabitants in which they can carry out their daily necessities. Therefore, a main tenet of ecological urbanism must be habitability, which refers to the ability of a city to respond to the needs of its inhabitants. We further argued that habitability should be divided into two categories: internal and external habitability. External habitability refers to the way cities function as systems, not only as systems implanted upon the landscape, but as integrated into the landscape, bringing the discussion back to the city as an ecosystem: ecological urbanism.

We proposed that a second tenet of ecological urbanism is sustainability, which refers to the management of resources and the production of waste, so that cities are viable for current and future generations.

To ground the theoretical discussion, we evaluated the informal settlement of La Primavera, Colombia using qualitative and quantitative techniques to see to what degree it meets with the tenants of Ecological Urbanism. The findings show that there are substantial concerns in terms of internal and external habitability and sustainability. For example, in terms of internal habitability, while the houses themselves meet standards for adequacy in terms of construction materials and space per resident, they do not have access to public infrastructures like water, electricity, gas, garbage collection or sewage. The residents have had to jerry-rig their own make-shift infrastructures in response to the lack of public service offerings. The most serious results of these systems are the contamination of land and water resources and the bad smells that are experienced throughout the settlement. Nonetheless, the external habitability of the settlement shows much greater deficiencies than the internal habitability as the settlement lacks access to schools, healthcare centers and even basic social facilities. Finally, in terms of ecological sustainability, the settlement is exceeding the carrying capacity of the land, and the populace is at risk from environmental threats like flooding, landslides, and collapse of the land into the riverbank because of erosion.

Yet, more than the just the settlement wide results, the case study of La Primavera demonstrates an incoherence in the development agenda in Colombia. On one hand, the State has guaranteed every citizen the right to a dignified living space in Article 51 of the 1991 Political Constitution. Furthermore, Decree 2190 of 2008 defines a dignified living space as a house that complies with the standards of habitability and quality in urban design, architecture, and construction, and has a monetary value equal to 135 legal monthly minimum salaries. *El Departamento Nacional de Planeación* (the National Planning Department) further states that to be habitable, a residence must provide healthy and comfortable environmental conditions needed for basic activities like resting, cooking, eating, personal hygiene and social relations. This definition incorporates aspects related to intangible variables that support human development, quality of life and social wellbeing. Furthermore, this same department adds another important component to the definition of a dignified residence, arguing that it must be sustainable from construction to habitation.

On the other hand, the National Government has also launched many environmental protection policies. One such policy is Law 99 of 1993, which seeks to protect the Aburrá River and the fragile ecosystems along the riverbanks by prohibiting the construction of public or private infrastructure. Another is Law 388 of 1997 which allowed the national government to declare territories restricted or otherwise protected. However, in establishing said policies and preventing the construction of infrastructure or failing to offer assistance in risk mitigation, the government has ignored the social and physical necessities of communities, especially resettled communities, which has resulted in further contamination of the natural environment. Thus far, government proposals have prioritized environmental conservation over sustainable intervention and management, and human wellbeing in settlements like La Primavera has therefore declined. Rather than taking a proactive approach to balance human and environmental needs, national and local governments have only offered palliative responses after a natural disaster strikes, resulting in both greater loss of life for the country's most vulnerable citizens and the greater destruction to the natural environment.

To make matters more complicated, the development projects designed by the State for the economic benefit of the communities of Valle of Aburra, like the local commuter train, put the population of La Primavera at further risk because due to both the environmental and social impacts.

[5] argues that “The sustainability of settlements is a multi-dimensional problem, dealing not only with settlement dimensions, but also with spatial characteristics, geographical location, environmental conditions, economic viability, institutional ability and structure, human development, social relationships, and local values and aspirations.” At the moment, however, the interaction of the legal, economic, environmental and physical conditions of La Primavera make life in the settlement untenable and unsustainable in the long-term. To become a viable place, State intervention is needed in relation to the environmental, economic, and social dimensions of the settlement.

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CIRCULAR MAKER CITY

A SPATIAL ANALYSIS ON FACTORS AFFECTING THE PRESENCE OF WASTE-TO-RESOURCE ORGANIZATIONS IN CITIES

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ABSTRACT

In recent years, the concept of the circular economy in cities (or ‘circular cities’) has been gaining traction among policy makers and urban planners. One strategy for circular cities is to locally convert waste to resources, which could be enhanced by the presence of ‘circular makers’ in cities: waste-to-resource organizations such as manufacturers utilizing waste streams for their production processes. Existing literature has identified a number of drivers and barriers that affect the presence of circular makers in a city, but the discussion has less focus on spatial perspectives, and instead examines policies and strategies of cities as a whole, without zooming in to smaller scales to understand neighborhood spatial characteristics. The aim of this research is to verify drivers and barriers from existing literature by answering the research question: How do space, people, and flow-related characteristics of neighborhoods affect the location of secondary resources received by circular makers? The research question was answered by conducting spatial analysis on the waste flow dataset of the national waste registry of the Netherlands - using Moran’s I to understand spatial clustering of various material and industry types, and Pearson’s correlation coefficient to understand relationships between the factors and secondary resources received. It was found that two industrial sectors (construction and agriculture) and seven materials formed strong spatial patterns. For correlations in the construction industry, flow factors resulted in correlations at both the country and regional scale, space-related factors resulted in correlations only at the regional scale, and people-related factors resulted in no correlations.

KEYWORDS

circular cities, urban manufacturing, waste-to-resource flows, spatial analysis,
sustainable cities, resource efficiency, eco-industrial development

INTRODUCTION

Cities have a large environmental impact - they consume 60-80% of natural resources globally, produce 50% of global waste, and 75% of greenhouse gas emissions [1]. In recent years, transitioning to a circular economy has been proposed by policy makers as a potential solution for cities. While there is no common definition for the circular economy, it is, however, generally understood as a closed-loop system that employs circular processes such as reuse, refurbishing, remanufacturing, and recycling to convert waste into resources [2]. To implement a circular economy at a city level, one proposed approach is to encourage local industrial activities in or near cities, minimizing the importation of raw materials and reliance on global supply chains [3]. This would be enhanced by the presence of ‘circular makers’: organizations that use processed waste as a secondary resource. In this paper, the word ‘maker’ is used rather than ‘manufacturer’ or ‘industry’, in order to include sectors that are not considered ‘industrial’ but still contribute to turning waste into resources, such as the construction and demolition industry or agricultural industry.

In a previous paper, a literature review and expert interviews were conducted to identify the drivers and barriers that affect the presence of circular makers in an area. These included space-related factors such as the affordability of land; people-related factors such as level of education for the local population; and flow-related factors such as the availability of waste in the area [4].

As a development from this previous research, this paper aims to empirically verify drivers and barriers from existing literature by identifying the statistically significant factors that affect the presence of circular makers in a certain location. This will be done by using spatial statistical methods to analyze the waste flow dataset from the Dutch national waste registry, in order to understand the spatial characteristics of areas that contain circular makers receiving a high amount of secondary resources. The research question for this paper is: How do space, people, and flow-related characteristics of neighborhoods affect the volume of secondary resources received? This research question is further divided into two sub-research questions: (1) Do the location of circular makers follow a spatial pattern? (2) What is the correlation between the amount of secondary resources received by circular makers in the construction industry, and the space, people, and flow-related factors?

Using spatial statistical methods, and the Netherlands as a case study, it was found that, for industry types, the construction and agricultural industry had the strongest spatial patterns. For material types, mixed wastes from sorting residues, vegetal wastes, mineral wastes, and fertilizers had the strongest spatial patterns. For correlations at the country level, flow factors had mild correlations, while the space and people-related factors had no correlations. When examining smaller regions surrounding hotspots, it was found that space and flow-related factors had mild correlations, while there were still no correlations for people-related factors.

THEORETICAL BACKGROUND

Overview of literature

Knowledge on the factors affecting the location of circular makers can be found in two domains - urban economic policy and industrial ecology; and two perspectives - ‘territorial’ and ‘company’. Studies from the ‘territorial’ perspective examine how the characteristics of a territory (such as population density or land value) have an effect on the location of companies. Studies from the ‘company’ perspective examine how characteristics of a company (such as type of industry, amount of materials processed) affect its location. While the fields of urban economic policy and economic geography tend to conduct studies from a ‘territorial’ perspective, industrial ecology studies tend to take a ‘company’ perspective.

Urban economic policy and economic geography

In a previous paper, a literature review was conducted on the space, people, and flow-related drivers and barriers to the presence of circular makers in an urban area [4]. Many of the papers in the literature review originated from urban economic policy research on urban manufacturing, which studies how economic and urban planning policy affect the presence of making activities within urban areas. While there was limited understanding on circular making activities, this body of literature gives a good insight on drivers and barriers for the presence of making activities in cities.

In terms of spatial factors, authors have found that the presence of making depends on the availability of affordable industrial land and manufacturing spaces [5], which in turn is affected by municipalities’ protective industrial zoning strategies [6], as well as the level of ownership and control municipalities have over their land [7]–[9]. A lack of industrial land can limit the

availability for both circular infrastructure (such as spaces for storage, collection and recycling materials) [10], [11], and manufacturing spaces [5], [6], [12], [13].

For people-related factors, authors found that makers locate themselves in urban areas in order to be closer to existing customers and support networks. Customers of makers can include wealthy environmentally conscious customers interested in locally-produced goods [14]–[16]; design or technology driven companies in need of customized making or prototyping services [6], [15]; as well as niche markets that require custom-made goods [13], [17]. Support networks can include skilled workers and professionals [6], [12], [18]; experts, consultants, and universities [14]; as well as marketing or business support [12].

For flow-related factors, authors have argued that circular making is driven by availability of municipal and industrial waste. The accumulation of municipal waste in cities gives an opportunity to recycle waste locally at the city scale [10], while industrial waste, which is higher in quality and quantity, gives more opportunity for circular processes to happen at an industrial scale [4]. The location of circular making is also driven by agglomeration of local production networks - circular makers tend to value proximity to large-scale traditional manufacturers [5], [6], [14], [19], as well as local supply-chains of smaller-scale manufacturers [6], [15].

The urban economic policy literature summarized in the previous paragraph is connected to the larger field of economic geography, which established location theory of companies. Here, authors develop spatial statistical methods to investigate factors affecting company location, such as the local municipal tax rate, labor laws, accessibility, as well as the local population's education level. Common factors investigated by economic geographers are: labor (such as education, unemployment), public sector interventions (such as taxation, infrastructure, funding), geography (local climate, elevation, proximity to the coast) [20], accessibility (proximity to transport infrastructure) [21], [22], as well as agglomeration (number of existing companies) [23], [24].

Industrial ecology

In the field of industrial ecology, authors have debated the benefits and trade-offs of different spatial scales of waste-to-resource flows - from industrial parks, to cities, to multi-city regions. Within this debate, some authors have explicitly identified the factors that allow for waste-to-resource exchanges to happen at a city or regional scale, advocating for the importance of industrial regions. Industrial ecology studies on circular makers mainly take the 'company' perspective, examining how the properties of a company (in terms of what materials and processes are being used) affect the geographical scale of its supply chain. For example, literature has found that the spatial scale of waste-to-resource companies is dependent on a variety of economic reasons with spatial constraints, such as transport costs, density of waste in an area, and service provision [25], [26].

Authors have also advocated for the industrial region (~30 km radius) as a promising unit for waste-to-resource exchange for eco-industrial development. According to case studies conducted in Germany, the industrial region is large enough to include a diverse collection of companies that would allow for waste-to-resource exchange, but small enough to minimize transportation costs [27]. Other empirical spatial studies on industrial symbiosis in the United Kingdom and China also found that the average distance between two industrial symbiosis partners was approximately 30 km [28], [29]. Additionally, authors have also examined how the properties of a material (such as its density or economic value) affects the distance it travels for waste-to-resource exchanges. Some authors found through case studies that high-value, low-volume goods are not spatially constrained and can travel long distances [30]. However, others found that there was no correlation between the weight or value of materials and the distance they traveled. Instead, it was dependent on the difficulty of reuse [28].

RESEARCH GAPS

Economic geography has a well-established body of research on factors affecting company location from a territorial perspective, which is supported by well developed and sophisticated spatial statistical models. However, economic geography literature has understandably paid less attention to factors related to spatial planning, such as accessibility, density, land use, land value, or level of urbanization. The amount of studies on circular makers is also limited, although factors affecting the location of manufacturing companies have been well described. Moreover, economic geography studies tend to examine cities or provinces as a whole (areas that have a diameter of around 30 - 100km), without zooming into smaller scales (3 - 10km) to find neighborhood attributes that could explain why circular makers are clustered in certain areas in a city and not another.

Industrial ecology, on the other hand, provides a deeper understanding of circular makers, as well as the spatial constraints of various waste-to-resource processes. However, studies lack a 'territorial' perspective, which explains how characteristics of a geographical territory (such as land value, accessibility, average income) could attract circular makers.

Research aim and questions

The aim of this research is to use spatial analysis methods with a territorial perspective from economic geography, as a tool to understand location patterns of circular makers in the Netherlands. The hope is to provide an additional perspective to existing knowledge on circular makers in industrial ecology, as well as insights to spatial planning for a circular economy at the city scale.

This paper's research question is: How do space, people, and flow-related characteristics of neighborhoods affect the location of secondary resources received by circular makers? In other words, why do secondary resources end up in one neighborhood and not another, and which space, people, or flow-related characteristics are they affected by? The two sub-research questions are: (1) Do the location of circular makers follow a spatial pattern? (2) What is the correlation between the amount of secondary resources received by circular makers in the construction industry, and the space, people, and flow-related factors?

METHODOLOGY

This research will use data from the national waste registry of the Netherlands to understand the level of spatial clustering of circular makers using spatial autocorrelation (sub-research question 1), and find correlations between space, people, and flow-related factors and the amount of secondary resources received by circular makers in each postcode (sub-research question 2).

Data source and processing

This study will utilize data from the national waste registry of the Netherlands (Landelijk Meldpunt Afvalstoffen, LMA), which records all waste flows larger than 50kg in the Netherlands that are processed by waste management companies, and includes information on the location of waste producers, processors, and secondary resource receivers; as well as the weight and material type of the waste flow. This study focused on the location of 'first receivers' ('eerste afnemers' in Dutch), which are non-waste management companies that receive processed waste as a secondary resource from waste companies. The focus was on 'first receivers' because they most resembled the description of 'circular makers', coming from various 'making' industries, such as construction and agriculture.

Using the LMA dataset, the amount of secondary resources received were calculated for each level 4 postcode in the Netherlands. Level 4 postcodes (e.g. 1011) were chosen instead of level 2 (e.g. 10) or level 6 (e.g. 1011 AA) because they were small enough to explain neighborhood differences (with a diameter of approximately 2 - 5 km), and large enough to prevent computational strain during spatial analysis. The secondary resources received per postcode were further categorized by industry and material type. Industry types were defined by the standard industry grouping code (SBI, Standaard Bedrijfsindeling) of the first receiver, which was found using an SBI code dataset from the Dutch chamber of commerce. Material types were already defined in the LMA dataset, using the European waste code (EWC) and the combined nomenclature code.

Finally, some flows in the LMA dataset were deemed as 'invalid' because the location of the first receiver in the dataset did not represent the true location of reuse, but rather the location of the headquarters of the company. These 'invalid' flows were removed with the help of waste experts from the Rijkswaterstaat, the Dutch government agency for public works. A full explanation of the data's limitations can be found in the limitations section.

Spatial analysis

Spatial autocorrelation

Spatial autocorrelation was used to understand whether the location of circular makers create a spatial pattern. Spatial autocorrelation describes the presence of systematic spatial variation in a variable. A positive spatial autocorrelation of a dataset would mean that areas closer together are more similar than areas far apart from each other. Moran's I, a measure of spatial autocorrelation, was used to indicate the level of spatial clustering for the top ten industries and materials in the dataset. A Monte Carlo method was used to estimate the statistical significance of spatial clustering. For each industry and material type, the Moran's I was calculated to quantify the level of clustering for the amount (kg) received per postcode - this is the 'observed Moran's I'. Then, in a simulation, the values were randomly reassigned to other postcodes, and the Moran's I is calculated again. This process of simulation was repeated 999 times, creating 999 simulated Moran's I's. Finally, the observed and simulated Moran's Is were compared, and if the observed Moran's I value is higher than 99.9% of the simulated Moran's Is (p-value of 0.001), it was considered as statistically significant. A p-value of 0.001 means that there is a 99.9% chance that the location of circular makers follow a spatial pattern and are *not* randomly distributed through space.

For each industry and material type, Moran's I was also used to identify the "hotspots, cold spots, doughnuts, and diamonds". "Hotspots" are high value areas surrounded by high value neighbors, "cold spots" are low value areas surrounded by low value neighbors, "doughnuts" are low value areas surrounded by high value neighbors, and "diamonds" are high value areas surrounded by low value neighbors.

Using spatial autocorrelation, industry and material types with significant spatial clustering were identified. With these results, a comparison was made between the industry and material perspective to understand which perspective is more strongly influenced by space.

Correlations

The step after spatial autocorrelation was to find correlations between space, people, and flow-related factors and the amount (kg) of secondary resources received by the construction industry at both the country and regional scale. In order to find correlations, space, people, and flow-related factors were identified from our previous research and industrial ecology and economic geography literature. The factors were then transformed into quantitative values that could be attributed to each postcode in the Netherlands. For example, the factor 'presence of industrial land' was transformed into the variables 'percentage of industrial land' and 'distance (km) from nearest industrial land'. The chosen factors are shown below in Table I.

Table I: Space, people, and flow-related factors chosen from existing literature

| Space-related factors | People related factors | Flow-related factors |
|---|--|--|
| Distance to nearest airport, seaport, freight train station, main road, industrial land; distance to nearest urban area, population density, area of industrial land, average household price | Percentage of people with low and high income, distance to nearest university, number of universities within 10km radius | Total amount of secondary resources received, waste processed, waste produced, amount received within 0-4km, 4-10km, 10-30km, 30-50km, and >50km |

Once the variables were identified, the variables with log-normal distributions were log transformed so that they followed a normal distribution. Then, the spatial lag of the variables was calculated, with weight distances of 4, 10, and 30km. A spatial lag is a variable that indicates the average of the neighboring values of a location. This allows for an understanding of not only the immediate attributes of each postcode, but the general attributes of its neighborhood at different spatial scales.

Finally, the Pearson's correlation coefficient was used to calculate the correlation between the amount of secondary resources received (kg) by the construction industry, and the space, people, and flow-related variables, including the spatial lag variables with weight distances of 4, 10, and 30km. A correlation value between 0.3 - 0.5 was considered a mild correlation, between 0.5 - 0.7 a moderate correlation, and between 0.7 - 1 a high correlation. Correlations were calculated for the whole of the Netherlands, as well as two smaller areas in the country that were hotspots for construction industry receivers - regions around the cities of Amersfoort (region A) and Eindhoven (region B). Correlations were also calculated for the data both with and without zero values.

RESULTS

Spatial autocorrelation

Two of the top ten industry types, construction and agriculture, had a Moran's I of higher than 0.1 and p-value lower than 0.001. A summary of the top 10 industries in the LMA dataset, their Moran's I values, and p-values are shown below in Table II. The hot spots, cold spots, doughnuts, and diamonds of the construction and agriculture industry are shown below in Figure 1.

Seven of the top ten materials had a Moran's I of higher than 0.1 and p-value lower than 0.001. A summary of the top 10 materials in the LMA dataset, their Moran's I values, and p-values are shown below in Table III. The hot spots, cold spots, doughnuts, and diamonds of the seven materials with a statistically significant Moran's I is shown below in Figure 2.

Table II: Moran's I and p-values of top 10 industry types by weight

| Rank (by weight) | Industry code and name | Observed Moran's I | p-value |
|------------------|--|--------------------|--------------|
| 1 | C - Manufacturing | 0.04 | 0.001 |
| 2 | E - Water supply; sewage, waste management and remediation activities | 0.02 | 0.012 |
| 3 | F - Construction | 0.13 | 0.001 |
| 4 | G - Wholesale and retail trade; repair of motor vehicles and motorcycles | 0.04 | 0.001 |
| 5 | A - Agriculture | 0.26 | 0.001 |
| 6 | H - Transportation and storage | 0.05 | 0.001 |
| 7 | K - financial institutions | 0.05 | 0.001 |
| 8 | M - Consultancy, research and other specialized business services | 0.03 | 0.01 |
| 9 | B - Mining and quarrying | 0.03 | 0.012 |
| 10 | D - electricity, gas, steam and air conditioning supply | -0.0 | 0.468 |

Table III: Moran's I and p-values for top 10 material types by weight

| Rank (by weight) | Material code and name | Observed Moran's I | p-value |
|------------------|--|--------------------|--------------|
| 1 | GNC 25 - Salt; Sulphur; earths and stone; plastering materials; lime and cement | 0.23 | 0.001 |
| 2 | ESV 12.8 - Waste from waste treatment | 0.19 | 0.001 |
| 3 | ESV 12.1 - Construction and demolition wastes | 0.2 | 0.001 |
| 4 | ESV 07.2 - Paper and cardboard wastes | 0.03 | 0.003 |
| 5 | ESV 12.6 - Soils | 0.14 | 0.001 |
| 6 | ESV 06.1 - Metal wastes, ferrous | 0.04 | 0.001 |
| 7 | GNC 31 - Fertilizers | 0.21 | 0.001 |
| 8 | ESV 09.2 - Vegetal wastes | 0.26 | 0.001 |
| 9 | ESV 10.3 - Sorting residues | 0.25 | 0.001 |
| 10 | ESV 06.2 - Metal wastes, non-ferrous | 0.04 | 0.001 |



Figure 1. Hot spots, cold spots, doughnuts, and diamonds of industry types with statistically significant spatial clustering: construction industry (left) and agriculture industry (right)

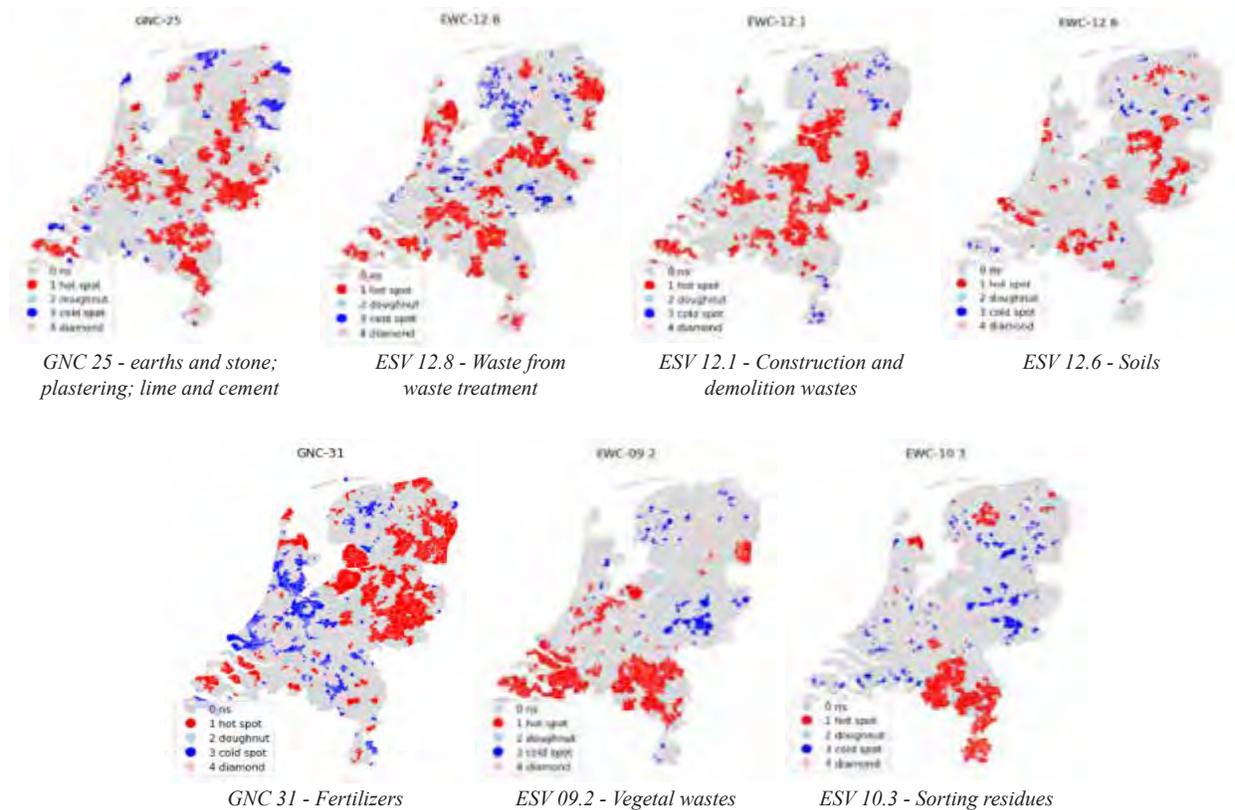


Figure 2. Hot spots, cold spots, doughnuts, and diamonds of material types with statistically significant spatial clustering

CORRELATIONS

Once the spatial autocorrelation was conducted, the construction industry was chosen to investigate the correlations between amount (kg) of secondary resources received and the previously chosen space, people, and flow-related variables. Correlations for space, people, and flow related factors are shown below in Figures 3, 4, and 5. In terms of correlations for the whole country, some flow factors (total amount of secondary resources received (regardless of industry and material), and total amount of waste processed) had a mild positive correlation. Amount received by the construction industry within 0-4km, 30-50km, and >50km had mild positive correlations, and amount received by the construction industry within 4-10km and 10-30km had moderate positive correlations. There were no correlations for the space and people-related factors, and no correlations for the spatial lag values of the space, people, and flow factors.

For smaller areas surrounding hotspots, more correlations appeared, although some correlation values differed between region A and B. For the flow factors in both regions A and B, additional mild positive correlation was found for the amount of waste produced, and a mild negative correlation was found for average amount of waste produced within 4km. For the space-related factors in region A, a moderate negative correlation was found for the average distance from the nearest industrial land within a 10km radius. For region B, mild positive correlations were found for distance from nearest industrial land and the average percentage of industrial land within a 10km radius; and mild negative correlations were found for average distance to nearest seaport for postcodes within a 10km radius, and average household price for postcodes within a 4km radius. For people-related factors, no correlations appeared for region A, and a mild negative correlation was found for the average percentage of people with low income for postcodes within a 4km radius.

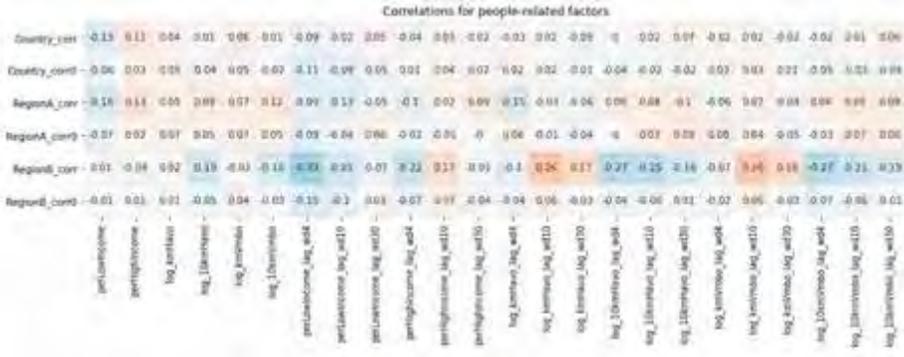


Figure 3. Correlations for people factors at the country and regional scale, with and without zero values

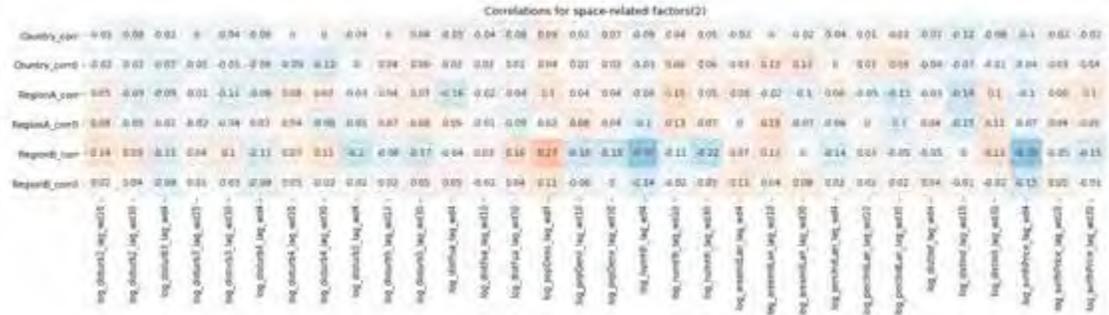
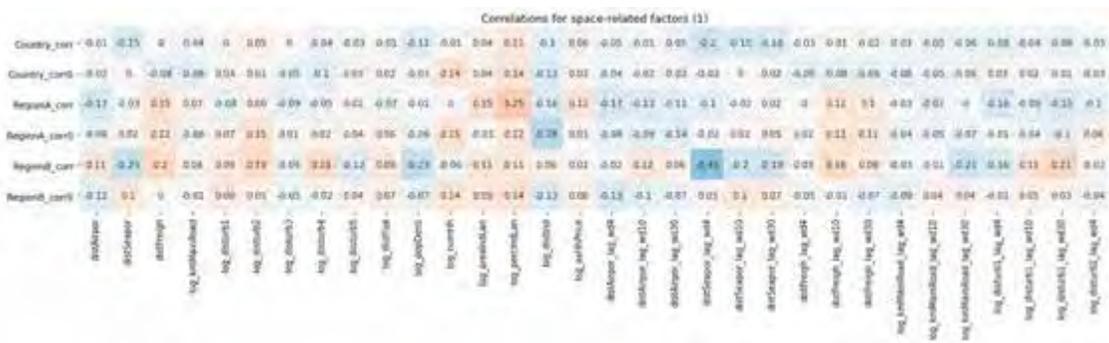


Figure 4. Correlations for space factors at the country and regional scale, with and without zero values

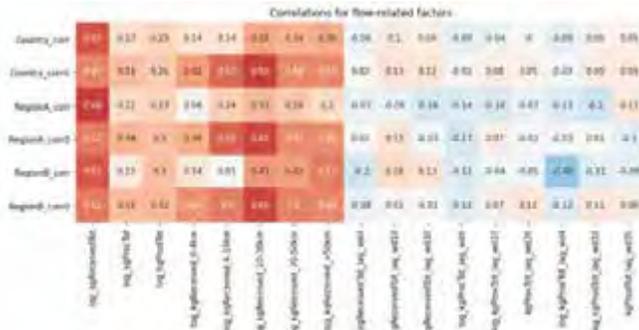


Figure 5. Correlations for flow factors at the country and regional scale, with and without zero values

DISCUSSION

Interpretation of results

Spatial autocorrelation results

When looking at the spatial autocorrelation results for the top 10 industries and materials, it can be seen that categorizing flows according to material led to more types with spatial clustering. In other words, flows categorized by material type (e.g. cement, vegetal wastes) instead of industry type (e.g. construction, agriculture) formed stronger spatial patterns. This might mean that companies using similar materials (e.g. wood) tend to cluster together regardless of what industry they are in (e.g. manufacturing, construction); whereas companies in similar industries (e.g. construction) do not cluster together regardless of what materials they use (wood, steel, cement). Thus, the spatial patterns in the Netherlands seem to be driven more by material than by industry.

This finding contributes to the existing discussion in industrial ecology literature on using a materials versus industry perspective when conducting material flow analysis. In the Handbook of Industrial Ecology, Bringezu and Moriguchi provided an overview of material flow analyses conducted by industrial ecologists, and separated them by materials versus industrial categorizations. They found that studies on materials leaned towards a technical engineering perspective and were useful for predicting possible effects of new technologies on material management; while studies on industrial sectors leaned towards a socio-economic perspective and were useful when comparing sectors to inform policy [31]. While the aim of this study is to provide insights to spatial planning policy, which would favor an industrial perspective, the spatial autocorrelation results found that a material perspective forms stronger spatial patterns. This is a tension that should be addressed in future research.

From the results, it can be seen that the level of spatial clustering for a flow type is not entirely related to the total amount (kg) of that flow type in the LMA data. This suggests that properties other than volume (e.g. value, processing type) may have an effect on the amount of spatial clustering. Finally, the results show that 6 material types and 2 industries with statistically significant Moran's Is, and are not randomly distributed through space. There is therefore benefit from conducting spatial analysis of these industries and materials, because their spatial clustering suggests that they are affected by location-related factors.

Country-wide and regional correlations

The results found that, in general, more correlations were found for smaller regions around hotspots rather than the Netherlands as a whole. Moreover, some factors' correlations differed between region A and B. This suggests that there are very few trends (only some flow-related factors) that can be generalized throughout the whole country. Instead, these trends vary from region to region. This may be because the amount of materials received is not a continuous variable across space and results in many postcodes with no value. As a result, areas with 'advantageous' spatial factors, might not have received any materials. There might also be other non-spatial reasons for the location of secondary resource flows, such as historical, economic, or even personal factors.

Flow-related factors had mild correlations at both the country and regional level. This suggests that agglomeration within the secondary resources supply chain plays a role in the location of secondary resource receiving circular makers. The correlations suggest that supply chain actors tend to attract each other and cluster together to form agglomerations, or that there is another hidden factor that might be attracting waste producers, processors, and receivers to similar locations. At the country level, there were no correlations found for the flow-related spatial lag factors. This suggests that co-location of secondary resource supply chain actors happens at the scale of a postcode (around 2-5km), but doesn't extend beyond the neighborhood, region, or city (4, 10, 30km).

Space-related factors had no correlations at the country level, but mild correlations at the regional level, although correlations differed between region A and B. This suggests that the effect of spatial factors varies from region to region. However, it is worth noting that distance from nearest industrial land is a common factor for regional A and B. Finally, people-related factors had no correlations at the country and regional level. This suggests that the location of secondary resources is not related to attributes of the population.

Limitations

Limitations of the LMA dataset

The results of this study is limited by the dataset used, which contained the waste data of the national waste registry (LMA) of the Netherlands. Firstly, the LMA data is limited from a ‘waste management’ perspective. A waste flow is only recorded in the LMA dataset if it goes through a waste management company, which means that industrial symbiosis exchanges between non-waste management companies are not included. As a result, most of the flows analyzed in this study have been processed with low-value circular economy processes such as recycling.

This study is also limited by the quality of data collected by the LMA on the location of circular makers (called ‘first receivers’ in the dataset). For many entries, the location recorded for the first receivers do not represent the true location of reuse, but rather the location of the headquarters of the first receiver. Around 30% of flows in the construction industry were considered to be invalid. This means that the final dataset that was analyzed for this study contained many ‘untrue’ zero values, which skewed the results for both the spatial autocorrelation and correlations. Moreover, around 20% of the data (by weight) could not be matched with the correct SBI code, meaning that for 20% of the flows, the industrial sector remains unknown. This could have contributed to the lower performance of the industrial perspective for the spatial autocorrelation part of the study.

Limitations of methods

The results of this study are also limited to the spatial analysis methods used to analyze the dataset. Moran’s I values for each industry and material type were only calculated at the country scale. There is a chance that flow types with stronger spatial clustering at the city or regional level, were not captured by the country-wide Moran’s I values. In other words, if the same Moran’s I method was conducted on a province or city, the level of spatial clustering for the industry and material flows might have been different.

In this study, the Pearson’s correlation coefficient was used to identify correlation between space, people, and flow related factors and secondary resources received. Pearson’s correlation only detects linear relationships, so more complex, non-linear relationships between variables have not been captured in the results. Moreover, correlation does not equal causation. For example, a positive correlation between A and B might mean that the A caused an increase in B; but it could also mean that B caused A, or that there is a third hidden factor that affects both A and B, that remains undetected in this study.

CONCLUSION

Summary of research

In conclusion, this paper aims to provide a spatial understanding on the presence of circular makers in cities by answering the research question: How do space, people, and flow-related characteristics of neighborhoods in the Netherlands affect the location of secondary resources received by circular makers in the Netherlands? The research question was answered by conducting spatial analysis on the waste flow dataset of the national waste registry of the Netherlands. Firstly, the level of spatial clustering of flows was examined by calculating the Moran’s I value of the top ten materials and industries in the dataset. Then, correlations between space, people, and flow factors and the amount of secondary resources received by the construction industry were identified by calculating the Pearson’s correlation coefficient on both the variables and their spatial lag with weight distance of 4, 10, and 30km.

It was found that two industries (construction and agriculture) and seven materials formed strong spatial patterns with statistically significant Moran’s I values. For correlations for amount received for the construction industry, flow factors resulted in correlations at both the country and regional scale, space-related factors resulted in correlations only at the regional scale, and people-related factors resulted in no correlations.

Recommendations for further research

Recommended further research directions respond to findings of this study, which is that the material perspective seems to form stronger spatial patterns than the industry perspective, and that there is a lack of trends that operate at a country level, but instead, trends seem to vary from region to region.

Since the materials perspective led to stronger spatial clustering, an investigation into the correlations for the material perspective could be beneficial. Additionally, the structure of the LMA data makes it easier to use the material perspective to trace flows from waste production, to processing, to receiving. This allows the possibility of extending the study beyond ‘first receivers’ or circular makers, to the entire waste-to-resource supply chain.

In response to the lack of spatial trends on the country level, other spatial analysis methods can be used to take into account regional level spatial trends. Firstly, instead of examining the entire dataset (~80% zero values), future research can examine only the statistically significant hotspots, cold-spots, doughnuts, and diamonds resulting from the spatial autocorrelation analysis. K-means clustering, which categorizes data into ‘clusters’ according to their attributes, can then be used to identify different ‘types’ or ‘clusters’ of hot spots, cold spots, doughnuts, and diamonds according to their space, people, and flow-related attributes. Geographically weighted regression (GWR), on the other hand, is a type of linear regression that takes into account the fact that dynamics between factors can vary across geographical space. Instead of creating one formula to describe the entire dataset (like linear regression), GWR creates one formula for each postcode to describe what is happening within its neighborhood. Using GWR, it is possible to understand how the effect of space, people, and flow factors changes across space.

Contributions

The findings and methodology of this paper is an attempt to show an example of using well-established spatial analysis methods from the field of economic geography and applying them to the topic of circular makers, in order to expand the existing discussion in industrial ecology on waste-to-resource flows at the city scale. While existing circular cities literature has a stronger emphasis on policy, governance, and material flows, this paper hopes to contribute a spatial perspective to understanding the topic. The spatial perspective of this paper allows for a more detailed understanding of the locations of waste-to-resource flows at the neighborhood scale, as opposed to the municipal, provincial, or even national scale; and also allows researchers to look beyond administrative and municipal boundaries when analyzing material flows.

Additionally, this paper investigated more factors affecting the location of circular makers from the perspective of spatial planning, such as population density, land use, land value, and accessibility. With further development, the hope is that this line of research could ultimately inform spatial policy, allowing existing circular city plans of municipalities to expand their reach beyond governance and economic policy, towards spatial and regional planning.

Author contributions and funding acknowledgement

Tanya Tsui was lead author and research lead for this paper. Arjang Tajbakhsh provided guidance in research methodology and coding in python. Arjan van Timmeren and David Peck provided editing and review work. This research received funding support from European Union’s Horizon 2020 research and innovation programme project ‘Pop-Machina’, under Grant Agreement No 821479.

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THE COMMON IMPACT MODEL: A STANDARDIZED METHODOLOGY FOR COMMUNITY ACCEPTANCE OF DECARBONIZED MULTIVECTOR LOCAL ENERGY SYSTEMS

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ABSTRACT

Today, cities, towns, and villages can increasingly power their electricity, heating, and mobility needs using clean and local energy sources. However, the successful and long-lasting adoption of clean and local energy solutions requires acceptance from different local stakeholders and community members. Our work presents the Common Impact Model (CIM), a structured hands-on methodology to facilitate community acceptance of Decarbonized Multi-vector Local Energy Systems. The CIM is designed for urban planners, energy managers, and those interested in establishing local energy systems and local energy communities. Underpinned by academic literature on the governance and social acceptance of collective energy solutions, the CIM comprises of 3-steps. In phase one, inputs are collected from key stakeholders using a community scoping questionnaire. The community's core values, priorities and practices are identified, as well as local stakeholders' rational and emotional reactions to proposed energy solutions. In phase two, data are analysed to visualise the different criteria that guide inclusive energy infrastructure planning. In phase three, engagement recommendations are co-created with the local partner using a tactical workbook. The CIM has been piloted in different contexts, including a harbour in Norway, a technological park in Spain, a township in South India. Based on the field experience, we provide recommendations for participatory planning of local clean energy solutions. The CIM is part of the E-LAND toolbox, a set of tools to establish, optimise and control multi-vector local energy systems, developed by the European founded Horizon2020 project E-LAND.

Video abstract available at: <https://youtu.be/BFY0zzxaJvc>

KEYWORDS

citizen engagement; community acceptance; renewable energy; energy communities; local energy systems

INTRODUCTION

1.1 Relevance and Problem Statement

Distributed renewable energy sources and smart grids allow generating power close to where it is consumed. Using these technologies, cities, towns, rural villages or industrial districts can become local energy systems (LESs), where local renewable energy sources power local most of the local electricity, heating and mobility needs. Local and clean energy generation helps communities mitigate climate change, support their local economy and increase the energy awareness of their members ([1]; [2]). In the European Union, LESs can be established and operated by an autonomous entity, known as “renewable energy community”. This entity manages the local collective energy assets and shares the output of local energy sources among its members, who are located geographically close to the energy production facilities ([3]).

Local energy systems and energy communities are regarded as a cornerstone for a just and inclusive energy transition, as they promote citizens’ participation in the energy transition and can accelerate investments in decarbonisation. Establishing LES, however, presents challenges ranging from selecting an optimal set of technological components, selecting an optimal business model, and settling conflicts of interest among the different stakeholders involved in the implementation ([4]). A techno-centric approach that ignores local and community acceptance can impede the realisation of energy projects and prevent the successful uptake of innovative energy solutions. Identifying local stakeholders and addressing their needs in an early stage is a success factor for establishing local energy systems ([5]).

With this work, we propose a structured process to design clean and local energy solutions that are compatible with local stakeholders’ views, values, and priorities. The Common Impact Model is a hands-on methodology for urban planners, energy managers, local authorities, and those interested in establishing decarbonised local energy systems and energy communities. It is a structured 3-step process to facilitate long-lasting acceptance of planned and existing energy innovation in a local energy system. It is based on the participatory energy infrastructure planning approach and uses an engagement strategy to facilitate local acceptance. The rest of this work is structured as follows. The rest of this chapter clarifies the definitions and features of local energy systems and renewable energy communities; Chapter 2 presents the theoretical framework of the CIM and, more specifically, reviews the literature on the drivers of social acceptance of local energy systems; Chapter 3 illustrates the methodology and reports on its recent applications; Chapter 4 concludes by providing recommendations for participatory planning of local clean energy solutions.

1.2 Definitions

A **local energy system** includes a group of geographically-close energy users that share locally produced power, as well as the soft and hard infrastructure required to generate, store and dispatch clean and locally produced energy ([6]) (**Table 1**).

Table 1: Typical and Distinctive features of a local energy system (LES)

| | |
|---------------------------------|---|
| Collective use | The energy infrastructure (RE generation units, infrastructures, storage units) is of joint use to a group of individuals |
| Geographical proximity | The members of a LES are geographically close to each other |
| Common good provision | A LES provides for a common good, namely energy and the avoidance of negative climate impact |
| Subtractability | One member’s consumption of the resource units makes those units unavailable to others: every kWh used by one consumer is not available to others. |
| High level of self-organisation | A LES typically features a dedicated governing institution. One type of governing institution is the “renewable energy community”. |
| Multi-vector | A LES typically requires the integration of many different energy vectors (electricity, heat) and technologies: renewable sources, energy-storage, active demand-side management solutions, smart grids |
| Citizen participation | Citizens and local organizations in a LES are typically involved in key decisions through different channels: information, consultation, direct or indirect decision-making power, financial participation. |
| Energy autonomy | A LES typically allows for a high level of energy autonomy for its members, defined as the share of local consumption met by local production.. |

A “renewable energy community” is a new legally autonomous entity that was defined in the latest EU energy package (“Clean Energy for All Package”) and has been transposed in Member States’ national laws [3]. The renewable energy community develops, owns and manages a local energy system. The renewable energy community shares the output of the generation facilities in the LES among its members, located geographically close to the energy production facilities. Its members can be private citizens, SMEs, local authorities, whereas traditional energy companies cannot be among its members. The renewable energy community should not be purely profit-oriented. Its main goal should be to provide environmental, economic or social benefits at community level to its shareholders or members or to the local areas in which it operates.

THEORETICAL FRAMEWORK: DRIVERS OF LES LOCAL ACCEPTANCE

Establishing and operating successfully a LES requires a functioning technology, a sustainable business model, and acceptance of the energy technology among multiple local stakeholders, such as potential energy users and producers in a LES, or financing actors for LES’s assets. Energy technology for LESs includes hardware and software solutions that satisfy people’s energy needs using local and renewable energy sources. Examples of such solutions are small or medium-scale renewable energy production assets (solar PV panels, wind turbine, biomass plant, heat pump) to be built for collective consumption of a group of stakeholders, a new local electricity distribution grid (microgrid), a demand-response scheme for the heating, ventilation, and air conditioning (HVAC) of a building used by multiple users, a new energy storage system or a charging facility for electric vehicles for collective use.

Depending on the desired energy configuration of the LES, successful implementation requires local stakeholders’ passive and/or active acceptance of energy technologies (Table 2).

Table 2: Two types of acceptance of energy technologies for LESs

| | Definition | Examples of the phenomenon | Example of a metric to assess the phenomenon |
|----------------------|---|---|---|
| “Passive” acceptance | Positive appraisal of the energy technology, whereby local stakeholders give one-off support to the project and do not oppose to it, while their energy-related behavior (how much/when/how they consume or pay energy) is not affected by the project. | Tenants living in a multi-apartment building vote for/do not oppose the realization of a new solar plan on their common roof | Adoption intention Likert-type scale, e.g.: “I will use e-car sharing in the future. I can see myself using e-car sharing in the future.” (answer options: I fully agree, I rather agree, I rather disagree, I fully disagree) |
| “Active” acceptance | Willingness to actively support the energy technology, whereby local stakeholders change their energy-related behavior to support the project | LES users change their consumption pattern, change their transport-fueling or mobility habits, invest in new energy equipment, co-finance the project, share data on their own consumption, lease their real estate property or land for hosting a new energy equipment | Attitude Likert-type scale, e.g.: “Generally speaking, e-car sharing services are a great idea. E-car sharing services offer a lot of benefits. (answer options: I fully agree, I rather agree, I rather disagree, I fully disagree) |

We review the literature on governance of commons and social acceptance of energy projects to identify factors that influence stakeholders’ passive and active acceptance of LESs. Insights from the following behavioural theories and conceptual frameworks have been integrated: Theory of Planned Behaviour ([7]), Ostrom’s principles for managing a commons ([8]), the framework for acceptance of renewable energies and smart grids ([9,10,11]). We categorize acceptance factors into: LES community’s features and LES stakeholders’ features. By “LES community” we mean the group of local stakeholders (either citizens or organizations, or both) that should either approve the energy technology or actively participate in it for the LES to be successful. The rest of this chapter summarises these factors.

2.1 LES Community features

a. Local ambassadors. Key committed individuals or entrepreneurs or organisations in a community, referred as “local ambassadors”, can be essential to success in establishing collective energy projects, such as energy communities ([12]). Distinctive features of local ambassadors are: high interest in the project, strong social bonds within the community, trusted by community members, knowledge of the local context, competence in the project, availability to provide information and ongoing communication on the project ([5]). Recruiting new members into a LES and winning support for it, in fact, depends upon personal contacts and neighbourly relations, as shown by the importance of “neighbourly appeals” in US community energy initiatives ([13]). Local ambassadors help build a common and understandable language, divert doubts and fears, advocate the project among other local stakeholders ([14]).

b. Easy conflict resolution and effective enforcement. Easy and low-cost resolutions of disagreements and conflicting interests between LES community members is one condition that facilitates the effective governance of common resources property, and therefore their long-lasting acceptance ([8]). In a LES the energy infrastructure is of joint use of a group and one group member’s consumption of the resource units makes those units unavailable to others. When subtractability exists, then collective use of resources could raise conflicts. Hence it is of foremost importance that a conflict resolution mechanism between LES community members exists, is easily accessible and low-cost, and allows enforcement of the rules. The conflict resolution mechanism and resource governing rules have to match local conditions. In particular, they may be different depending on whether the LES is decentrally operated (many members owning assets and sharing energy, i.e. residential prosumers) or centrally operated (one professional actor owning and managing energy resources and sharing energy to others).

c. Community identity. Robust governance of localized resources requires a clear definition of the boundaries of common resources and their users ([8]). A strong community identity facilitates a clear definition of who LES users are. Strong community identity translates into a sense of attachment to the group, a feeling of taking pride in the community, and having friends within the community ([15]). The stronger the citizens’ social identification to a group, the higher is their willingness to contribute to the community and actively support community energy projects ([15]). The importance of community identity in the successful establishment of an energy community is also supported by empirical network theory studies, which show that similarity in individual characteristics (“homophily”) causes the formation of network ties ([16]).

d. Relatedness / Mutual trust between community members. A sense of trust is needed to achieve a high acceptance and willingness to participate in community energy projects ([17, 15]).

e. Connectedness. Network theory studies suggest that ties in one kind of network favour ties in other kinds of networks (“multiplexity”) ([18]). Citizens/companies who already had a close interaction (e.g. shared association, joint project), are more likely to be happy to be grouped together in a LES or energy community. Early work on energy autarkic regions already suggested that an increase in interactions between people, is perceived as desirable by consumer-citizens and could become a driver of decentralized energy systems ([19, 20]).

2.2 LES stakeholders’ features

We identify three individual-level factors that influence acceptance of LES, based on the Theory of Planned Behaviour ([7]), which has been already successfully applied to explain the adoption of energy-related innovation (see amongst others: [21,22]).

a. Perceived behavioural control. In the case of active acceptance of energy technology, the final decision to participate in the energy technology implementation hinges on whether the stakeholder feels capable of participating. In the context of a self-consumption scheme, for example, the fact that one stakeholder does not have (or perceives not to have) decision power on the choice of their energy supplier impedes active participation. Financial and knowledge-related factors typically influence perceived behavioural control (e.g. adoption cost perceived as too high, offer considered too complex to understand).

b. Subjective social norm. Whether a stakeholder perceives social pressure from his/her peers to accept the energy technology or not, matters for acceptance. Stakeholders’ acceptance of the energy technology depends on whether they believe that important reference groups/peers approve or disapprove it. In the context, for instance, of a ground-mounted solar power plant built for the neighbourhood’s electricity consumption, feeling that neighbours would like to join in the self-consumption scheme may increase individual acceptance. Endorsement from trusted sources could be very effective in fostering acceptance, as well as visible support from influential members of the local social network, such as local ambassadors.

c. Attitude towards the technology. Stakeholders' attitude is formed by:

- a rational evaluation of the new energy technology and the related project's attributes (e.g. location, financial model);
- emotional reactions to it;
- individual values ("worldviews").

The rational evaluation follows from **stakeholders' views on the solution**: perceived benefits/positive effects, perceived adoption costs/drawbacks/negative effects, perceived risk, perceived barriers, perceived cost/benefit distribution (fairness). Such views are mediated by individual stakeholders' features, and in particular: **knowledge and salience** of energy topics, and **familiarity** with energy technology. Energy knowledge and energy literacy allow informed evaluation of the technology. As stakeholders often display limited mental processing capacity, salience of energy topics increases interest for the energy technology and the likelihood that the stakeholder considers participation. Familiarity reduces perceived risk and can explain why often local acceptance vary over time, and in particular before, during and after implementation of an energy project, due to a learning effect ([23]; [9]).

Furthermore, stakeholders' views depend on technology features and the related **project's attributes** (location, financial model, developer, procedural and financial participation level, etc.). In particular, procedural and distributional justice aspects matters for social acceptance of renewable energies ([24]) and LES ([4]). Procedural justice is ensured by fair participatory planning processes, while distributional justice is ensured by a fair allocation of costs and benefits of the technology. Different increasing degrees of stakeholders' involvement are possible in the technology planning process: information, consultation or public hearing, delegated power, referendum (representing the highest degree of participation, including a veto right) ([25]). An improvement in perceived distributional justice, for example through shares of local co-ownership and/or local benefits (e.g. new jobs) for the community, tend to improve the acceptance of distributed energy infrastructures ([4]). Studies on the governance of common resources, however, show that there is no single type of local financial participation and asset ownership (government, private or community) that uniformly supports good resource management ([10]). The suggested approach is context-specific, one that matches ownership and governance constructions with local stakeholders' procedural and distributional justice preferences ([10]).

Emotions towards energy technology influence attitude. In particular, studies have investigated both the cognitive underpinnings of energy-related preferences, as well as affective factors (see amongst others:[26]. According to the affect heuristic proposed by Slovic et al. [17], people base their judgments and decisions on the positive and negative feelings that arise in relation to a stimulus.

Finally, **individual values (or "worldviews")** could lead to a positive attitude towards LES energy technology: collectivism (or "societal interest value orientation", defined as a preference for being a member of the group rather than apart from the group), environmental concern, climate change awareness, positive attitude towards technological innovation, willingness to pay for renewable energy and/or local energy, place attachment. Particularly when local stakeholders have strong emotional and cultural connections to a place (i.e. display high place attachment), a new energy technology is more likely to be accepted when it is not perceived as something "out of place", something that does go not against the local values: an acceptable technology does not ruin the place distinctiveness and historical continuity ([28]).

3. THE COMMON IMPACT MODEL METHODOLOGY

The CIM is a structured process designed for urban planners, energy managers, and those interested in establishing and/or operating local energy systems and local energy communities. The CIM is the community tool of E-LAND toolbox, a modular set of tools to establish, optimize and control multi-vector local energy systems. The goals of CIM are to:

1. Identify the local stakeholders who matter for successful implementation of new energy solutions and/or who are affected by a new way of operating existing energy infrastructure.
2. Assist a local partner in designing energy solutions in a way that is compatible with local values and priorities, taking into account perceived benefits and concerns of local stakeholders
3. Help the local partners develop a strategy to engage local stakeholders and hence facilitate long-lasting acceptance of new energy solutions.

Through community engagement and dialogue with stakeholders, the CIM builds acceptance for local solutions for the energy transition, including collectively shared renewables, local energy communities, energy islands, citizen co-financing of local renewable energy projects, energy peer-to-peer trading schemes. The analytic deliberation principle inspires the CIM approach: a well-structured dialogue involving scientists, resource users, and interested institutions, and informed by analysis of key information about environmental and human-environment systems ([8]). Analytic deliberation provides improved information and trust, builds social capital, and can deal well with inevitable conflicts ([8]).

The CIM comprises of 3 phases, each phase is matched with a tool that helps scalability and replicability to different contexts (Figure 1). An intermediary takes the lead for the application of the methodology. The intermediary works in close collaboration with a local urban planner, energy manager or another type of local private or public actor interested in establishing and/or operating a local energy system that is compatible with local stakeholders’ needs, priorities and values.

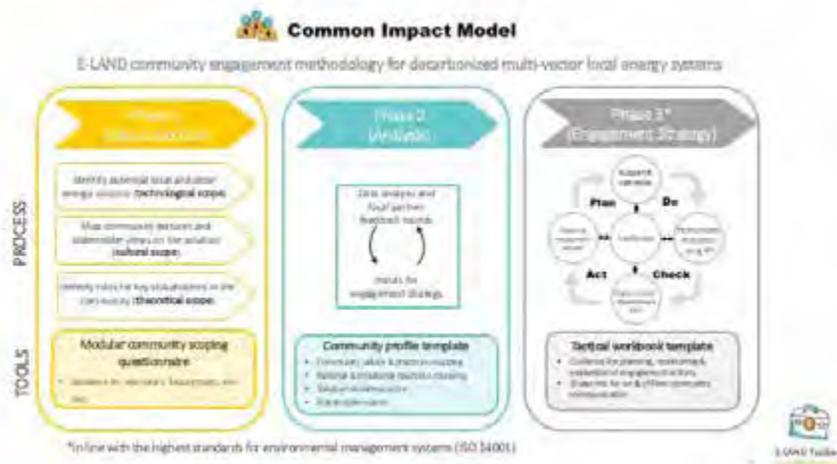


Figure 1: Common Impact Model

Phase 1 is about collecting inputs from key stakeholders and the tool associated is a modular community scoping questionnaire template, made up of 3 main modules. Module 1 (**technological scope**) identifies the clean and local energy solution to focus on and it is conducted with a local partner (Table 4). Module 2 (**theoretical scope**) identifies the relevant stakeholders and uses a stakeholder analysis method ([29]) to map them according to their interest in the solution and influence in its implementation (Table 5, Figure 2). Module 3 (**cultural scope**) maps the community and stakeholders’ features that influence acceptance of the solution identified in Module 1 (Annex 1). These features are based on a review of the literature on governance of commons and social acceptance of energy projects (see Chapter 2). In Module 3 the community’s core values, priorities and practices are identified, as well as local stakeholders’ rational and emotional reactions to proposed energy solutions.

Table 4: Template for Module 1 of community scoping questionnaire (technological scope)

| Discussion guide text/survey text to local partner |
|--|
| <p>The aim of this section is to identify and briefly describe a project where to focus our engagement efforts at XXX. The project has the following features:</p> <ol style="list-style-type: none"> 1. your organization would like to start to implement the project in XXX 2. for successful implementation of the project, your organization need approval or active participation of other individuals/organizations (e.g. other companies in XXX, building owners in XXX, people living in XXX, local authorities in XXX, financing bodies) <p>We understood that your organization would like to <i>[establish an energy community, install a wind turbine generating power for the nearby village, install a solar PV system on a common roof for collective use of a group of energy users...]</i>. Did we understand this right? Can we focus on this project?</p> |
| <p>Image you have to present the project to your local stakeholders. How would you describe it (2-4 sentences)? <i>[Note: after this section the “solution” (or “project”) is identified, the rest of questionnaire will refer to it.]</i></p> |

Table 5: Template for the Module 32of community scoping questionnaire (theoretical scope)

| Discussion guide text/survey text to local partner |
|---|
| <p>Next we'd like to identify the stakeholders who might be important for the successful implementation of [solution].</p> <p>Please name the relevant stakeholders for the implementation of [solution] and then position each actor in a matrix, defined by two dimensions: 1. Influence on other stakeholders and in the decision process (someone whose advice has great influence would score high on influence) and 2. Interest in solution (someone who is enthusiastic about the solution would score high, someone who is expect to oppose score low). <i>[After placing each stakeholder, ask "why?" to get qualitative insights.]</i></p> |
| <p>Let's look back at the stakeholder matrix that we compiled together.</p> <ul style="list-style-type: none"> • Which stakeholder do you meet or talk with at least once a week? • Which stakeholder do you meet or talk with at least once a month? • Are you and other stakeholder part of the same association, organization, board, club? • Which stakeholders do you have a good relation with? • Do certain stakeholders have a close relationship with some of the others? |

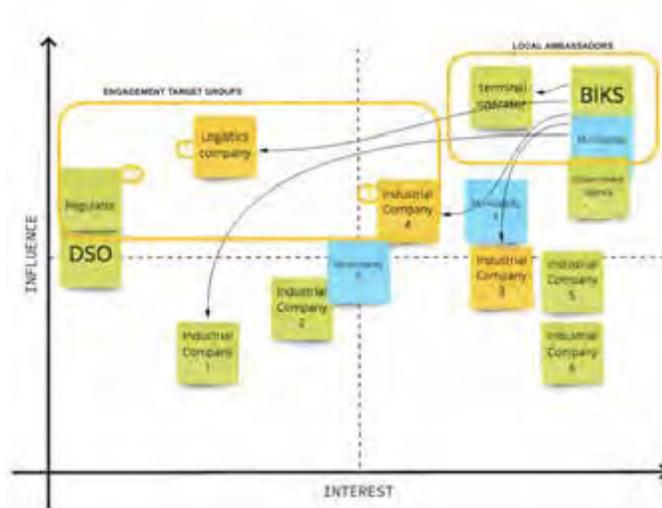


Figure 2: Stakeholder matrix compiled for a pilot application

In **Phase 2**, inputs from Phase 1 are summarised in the community profile template (**Figure 3**). This template visualises the different criteria that guide inclusive energy infrastructure planning:

- The **readiness score** measures community's readiness to accept local and collective clean energy solutions, it is average score over the score assigned to 10 key community values: environmental concern; climate change awareness; willingness to pay for renewable energy; willingness to pay for local energy; attitude towards innovation; collectivism; community identity; place attachment; mutual trust; connectedness: It helps choose the types of engagement actions: high score suggest to focus on deployment (recruit leaders/governing body, share results and disseminate impact); a medium score suggests to focus on development (co-creation workshops); a low score suggests to focus on exploration (build basic knowledge).
- The **measure for attitude towards the solution** assesses the starting point of acceptance (baseline). Engagement strategy can be evaluated by comparing this measure before and after the engagement actions.
- **Ranking of perceived benefits and concerns** help choose a message framing for communication campaigns and design the solution in a way that maximise positive aspects and addresses concerns. Information on perceived benefits and concerns help frame messages in a way that addresses concrete consequences for stakeholders.
- **Ranking of barriers** helps design engagement actions, one engagement action for each major barrier can be designed.

- The **stakeholder matrix** helps segment stakeholders. Local stakeholders can be divided into proponents of the solution (high interest), those with weak preferences for the solution (low/medium interest), opponents of the solution. Different actions can be targeted to each of them. Typically, a top-priority target for engagement actions would be composed of highly influential stakeholders who are not interested in the solution. Local ambassadors are stakeholders with high interest and high influence. They should be recruited as partners for engagement actions. Local ambassadors could be the local trusted contact persons/organisations. They establish from project start to project end (and at best beyond this) an ongoing communication with energy users interested in/affected by the project.
- **Emotional reaction mapping:** a sense of emotional connectedness with the new energy infrastructure is one of the success factors for successful implementation of energy projects and local energy systems ([4]), so leveraging on positive associations with the technologies, as elicited using the questionnaire, help build acceptance.
- **Procedural and distributional justice preferences' assessment** helps design ownership and governance constructions for the LES that match local stakeholders' preferences.



Figure 3: Community profile compiled for a pilot application

In **Phase 3**, with the help of the tactical workbook (**Table 6**), engagement recommendations are co-created with the local partner.

Table 6: Tactical Workbook Template (compiled for a specific action of a pilot application)

| | |
|---|--|
| Barrier #2: Opposition to new gridlines | Action: Educate residents about <i>why</i> local grid connections are needed and <i>how</i> it will impact Auroville as a whole. Invite residents to communicate their opinions and ask experts for more information. |
| Objectives | The barrier is largely due to a lack of awareness. Address knowledge gap and build acceptance of local grid connection and get an overall buy in from the community for a carbon-free electricity sourcing. Connect homes to local grid. |
| Description | Provide educational resources by sharing information in small, digestible chunks in internal intranet. If possible, bring the discussion to the target group by arranging/promoting it around an existing event (e.g. monthly steward meeting) |
| Target audience | Residential Assembly; Town Development Council |
| Materials | Communication package |
| Timeline | The winter/rainy season is the best time to address these topics |
| Key Performance Indicator | Willingness to join the local grid (measured with survey), pre/post action; number of off-grid homes |
| Cost | To be defined by Auroville Consulting |
| Leadership | Auroville Consulting |
| Local ambassador | Expert 1 |

The CIM is dynamic model - and therefore, phases 1 and 2 could (and maybe should) be repeated overtime after phase 3 to ensure the changing dynamics of the community are captured and factored into future engagement recommendations. This feature of the CIM is inspired by the plan-do-check-act cycle, in line with the highest standards for environmental management systems (ISO 14001).

The CIM has been piloted by the E-LAND Community Building team in different contexts, including a sea port in Norway, a technological park in Spain, a residential township in South India (**Table 7**)

Table 7: Pilot applications for the Common Impact Model

| Pilot site | Location | Proposed energy solution | Local partner | Local partner evaluation |
|--|------------------------|---|---|--|
| Auroville , small township-based community with 3000 residents powered by a mix of grid and on-site renewable energy | southern part of India | Installing new solar systems and battery storage in Auroville | Auroville Consulting, unit of a local non-profit organization | 3/4(“Rather satisfied”) Favourite features: stakeholder matrix, engagement |
| Port of Borg , sea harbour in an industrial area, hosting diverse companies, incl. recycling plants, district heating, food industry | Norway | Shifting from fossil-fueled heavy trucks to electric trucks at the port, leveraging on local e-chargers | Borg Havn IKS, a small organization and owns and operates many buildings, along with the harbour itself | Not yet available (application in process) |
| WALQA technology park , an initiative run by regional government and the local city council. It hosts about 1000 workers and 60 companies, mostly small tech companies or start ups | North East of Spain | Establishing an energy community at WALQA technology park | Inycom, a large technology company with several offices throughout Spain | Not yet available (application in process) |

4. CONCLUSIONS

Today, cities, towns, rural villages or industrial districts can become decarbonized local energy systems (LESSs) and renewable energy communities, where local renewable energy sources power most of the local electricity, heating and mobility needs. Successful and long-lasting LESSs and energy communities require a functioning technology and a sustainable business model, and acceptance from different local stakeholders and community members.

With this work, we propose a hands-on methodology to facilitate the acceptance of LESSs and solutions that generate energy close to where it is consumed. Underpinned by academic literature on the governance and social acceptance of collective energy solutions, the Common Impact Model adopts the inclusive infrastructure planning approach. It helps design clean and local energy solutions that are compatible with local stakeholders’ views, values and priorities. The Common Impact Model is structured in 3 phases, each matched with a tool that helps scalability and replicability: a scoping questionnaire for Phase 1 (data collection), a community profile template for Phase 2 (analysis), a tactical workbook template for Phase 3 (engagement strategy).

Based on the experience in designing and piloting the CIM at different locations, we conclude by summarising its five recommendations for participatory planning of local energy systems and energy communities:

- 1. Identify and map local stakeholders.** Sorting them according to interest in the solution and influence in its implementation allows identifying local ambassadors and the main engagement target groups.
- 2. Understand local stakeholders’ values, priorities and practices.** Solutions compatible with local values and addressing community priorities are typically successful.
- 3. Understand local stakeholders’ views and emotions towards energy technologies and solutions.** It helps adapt accordingly project design and communication.
- 4. Develop an ongoing engagement strategy with dedicated resources and leadership.** The strategy consists of a limited number of specific engagement actions that overcome barriers, are designed for the main engagement target groups and involve local ambassadors. The strategy should not stop once the construction permit is granted or the technology is operating, it should be adjusted after monitoring its impact using pre-defined key performance indicators
- 5. Facilitate accessible and low-cost conflict resolution mechanisms.** This mechanism addresses concerns, prevents negative spill-overs and mitigate the risk of facing strong opposition, which usually comes from vocal minorities.

ANNEX I Questionnaire items used in Module 2 of community scoping questionnaire (cultural scope)

| Community features | |
|---|--|
| Factor | Questionnaire Item(s) |
| Easy conflict resolution and effective enforcement. | Conflicts and disputes in ... are resolved in an accessible and low-cost way (^) |
| Community identity | Organizations working in ...often talk about ... as being a great place to be and work/ People living in.... often talk about ... as being a great place to be and live (*) |
| Relatedness / Mutual trust | Companies working in ... in general trust each other / People in general trust their fellow community members in ...(*) |
| Connectedness | It is common to talk to each other when people meet in ...(*) People often spend time with other people working/living in ...(*) How often do you/your company interact with other organizations/people in...[alternative:] How often do you interact with [+ list of stakeholders]; are you part of the same board, association? |
| Stakeholders' features | |
| Factor | Questionnaire Item(s) |
| Perceived behavioral control | Your organization/You can substantially influence/can decide on the approval and implementation of this project/can participate in this project (^) |
| Subjective social norm | In your opinion, how many groups/organizations/people in ... would support this project? |
| Attitude (general) | Your organization/you would be motivated to invest time and financial resources to support this project (^) |
| Perceived benefits/positive aspects | What would be the main benefit(s)/positive aspects of this project in your opinion? |
| Perceived adoption costs/negative aspects | What would be the main downside(s)/negative aspects of this project in your opinion? |
| Perceived fairness | In your opinion, would some groups/organizations in ... benefit from this project significantly more/less than others? |
| Perceived risks | What would be the main risk(s) to this project in your opinion? |
| Perceived barriers | What would be the main barrier(s) to this project in your opinion? |
| Knowledge | <ol style="list-style-type: none"> 1. People in ... know how much they spend on their electricity (^) 2. People in ... know how much they spend for cooling their buildings (^) 3. People in ... know how much they spend on their transport needs (^) |
| Salience | How would you describe the amount that you/your company pay for electricity / cooling/ heating own building/ transport fuel? |

| | |
|---|---|
| Familiarity | How many people in ... are used to seeing the following in their immediate surroundings:[list of relevant technology components of LES] |
| Emotional reactions | What is the first word or phrase that comes to mind when you read ...:[list of relevant technology components of LES] Can you tell me whether the word(s) or phrase(s) you indicated has a (very) positive, (very) negative or neutral connotation? |
| Environmental concern | Looking after the environment, caring for nature, saving resources is important to you/your organization (*) |
| Climate change awareness | You/Your organization is ready to recommend friends & colleagues /colleagues & workers activities that will help reduce global warming or to live a clean and green life (*) |
| Willingness to pay for renewable energy | Your organization/you would be ready to pay more energy produced from renewable energy sources compared to energy produced from fossil fuels. (*) |
| Willingness to pay for local energy | Your organization/you would be ready to pay more for energy produced from local energy sources compared to energy from the transmission grid (*) |
| Attitude towards innovation/ technical affinity | You/People in your organization are reluctant to try new technologies (*) |
| Collectivism | Your organization often does joint initiatives with neighbouring companies/ You like sharing little things with their neighbours (*) |
| Place attachment | People in your organization/you feel a very strong sense of belonging to ... |
| Procedural participation preferences | According to you, how should you/your organization and [other LOCAL STAKEHOLDERS] be involved in the project? Please select one or more options * informational action (e.g. event, brochure) * consultation /public hearing * through the work of elected representative bodies * referendum (including veto right) * direct involvement of [LOCAL STAKEHOLDERS] is not necessary * Other ____ |
| Financial participation preferences | According to you, how should this project be mainly financed? Please select one or more options * external donations * government money * internal funding * Involving [LOCAL STAKEHOLDERS] (e.g. fund-raising from individuals) * Other ____ |

(*) the respondent has to assess how well, according to him/her, the description matches him or her/his or her organization.

(^) the respondent has to assess to what extent he/she agrees with the following statement (s)

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ⁱ Local energy systems are also known as “local distributed energy systems”, “local energy hubs” or “integrated multi-energy systems” or “smart grids for distributed generation”.

ⁱⁱ Key legal references: “Clean Energy For All Europeans”, COM(2016) 860 final, November 2016; EU Directive 2019/944; EU Directive 2018/2001.

ⁱⁱⁱ More information on E-LAND Toolbox can be found at: <https://elandh2020.eu/>

^{iv} For a non-technical summary of CIM application at Auroville, refer to: <https://elandh2020.eu/news/making-green-energy-aspirations-a-reality-in-india-how-the-e-land-community-engagement-methodology-is-supporting-the-development-of-energy-communities/>.

CULTURE OF SUSTAINABILITY AND THE BIOSPHERE ECO-CITY

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ABSTRACT

Human pressures are changing the Biosphere, Earth's outer shell of land, water and air that supports all life. In its new form, the Biosphere will support fewer current species, including our own. Education, science, and sustainable cities are reducing human impacts, but not quickly enough. Most of the world's over-3000 cities lack elements needed to quickly become sustainable and collectively prevent the Biosphere from morphing to a new form. We need balanced social-ecological systems in tune with the resilience of the Biosphere. A culture of sustainability can support the evolution of such systems. We can create this new culture by engaging 10% of the people in a city in sustainability, and it will emerge automatically. Using human capital – the energy and ideas of people – as a main resource, this culture will produce sustainability in poorer cities and complement planning and scientific approaches in wealthier cities. A Biosphere Eco-City (BEC) is an urban-rural region where engagement of people and organizations creates a culture of sustainability. BEC's 10 Themes represent all areas of direct action for sustainability and bring together people with common interests. Its 10 Tools engage people through understanding, involvement, innovation and sharing. Tools identify issues and lead to projects. Ottawa BEC has been testing the Themes and Tools since 2009. In 2021 it linked to initiatives in four more cities to create BEC Canada. Any group interested the BEC approach for their city may read about it on the BEC Canada website, and through it request manuals and advice.

KEYWORDS

Biosphere, Sustainable, Social-ecological, Culture, People, Engagement, Eco-City

INTRODUCTION

Reconciling the actions of Humanity with the Biosphere is essential to conserve living conditions as we know them. Science, education, and sustainable cities produce great results, but are not enough to prevent the Biosphere from morphing to a less desirable form. This paper explains how a culture of sustainability will enable social-ecological systems in tune with the resilience of the Biosphere. The Biosphere Eco-City approach engages people in any city to create this culture. It has been tested and information on its use is available via the Biosphere Eco-Cities Canada website.

ARTICLE

The Biosphere and Humanity

The Biosphere, the Earth's outer shell of land, water, and atmosphere, contains all life. It is self-regulating and incredibly complex. All life, from the plants and deep-sea crabs in ocean trenches to birds in the air are supported by the Biosphere. This 'sphere of life' exists in constant balance with those smaller parts of itself in which we live – biomes and ecosystems. As those parts become degraded by deforestation, pollution, climate change and other human impacts, they begin to change the Biosphere. Creating a global home that is less supportive of many current lifeforms, including Humanity.

Other huge natural elements surround the Earth too and the Biosphere interacts with them. The Atmosphere is the air surrounding the Earth. The Lithosphere is the layer of rock and sediment that extends for many kilometers into the Earth. The Hydrosphere comprises all the Earth's water, including oceans, water on land, in the Atmosphere, and in ice sheets. Human pressures affect these elements as well, and their distortions can also put pressure on the Biosphere.

The Biosphere is a robust system, which has developed and evolved over a very long time. It receives its energy from the sun, and depends on the Atmosphere, Lithosphere, and Hydrosphere for its existence as well. The Biosphere gets its vitality from the life within it. In return it maintains stable conditions for an uncounted number of lifeforms. Human activity that significantly impacts other life forms, radically changes natural energy flows, or alters any other large elements of the Earth, will change the Biosphere.

How do we preserve the Biosphere in a form with which we are comfortable? By changing how we live and work to ways that are in harmony with the Biosphere.

Significant efforts to reduce human wrongs against nature and the Biosphere followed the 1962 publication of "Silent Spring" [1], the 1968 UNESCO "Biosphere Conference" [2], and the 1972 publication of "Limits to Growth" [3]. Two generations of Humanity have now tried to protect the Biosphere through science, international programs, education, laws, and planning. Much has been accomplished and people can be justly proud of their electric cars, ecocities, and the sustainable development programs operating around the world. If there were enough time, this work on multiple fronts would neutralize Humanity's negative impacts on the Biosphere. But there is not enough time to rely on these features alone.

Sustainable Cities

Planning of sustainable cities or eco-cities has received a lot of effort. Dozens of examples around the world inspire us including Copenhagen, Curitiba, Frieberg, Malmo, Nantes, Portland, and Vancouver. This work should definitely continue.

Eco-cities are important for three main reasons:

- They significantly reduce a city's environmental footprint
- They export sustainability practices, because of cities' global outreach
- They improve quality of life for millions of urban dwellers

To become sustainable, a city needs all the following elements:

- All levels of government aligned for sustainability
- Enabling legislation and adequate planning systems
- Sufficient expertise in planning and science
- Adequate funding for plans and projects
- Enough time to not be overwhelmed by growth

Unfortunately, most of the world's over 3000 cities do not have all these elements, and their social and environmental problems are increasing. With their current resources they cannot become sustainable in time to collectively prevent the Biosphere from morphing into a new form. A new approach is needed.

While millions of people want to solve environmental issues, their focus is often quite specific – save whales, protect farmland, clean water, eliminate toxic waste dumps – all of which are very important. Yet “There is a real lack of understanding of what the problem is – maintaining and restoring the carrying capacity of the Earth” [4]. In other words, protecting the health and resilience of the Biosphere.

Karl Folke, a world expert on resilience, wrote “we need balanced social-ecological systems in tune with the resilience of the Biosphere” [5]. So, we need to create social systems for Humanity – billions of people – that integrate nature to allow the Biosphere – all life on Earth – to rebound in natural ways. In other words, harmonize two systems of incredible complexity.

We can do this by creating a culture of sustainability. A culture in which sustainability is integrated into the decisions of everyone.

Culture

Let's consider how culture operates. Culture develops from people's lived experiences and countless interactions with the environment. Culture is an agile system. It constantly adapts and can be an intermediary between people and the environment. As culture grows, it guides human actions. It changes Humanity.

A well-known example is the culture of Agriculture. For over 10,000 years people experimented with crops and animals. This profoundly changed Humanity and led to the development of cities, nations, and international trade.

A culture of technology grew over the past 1000 years and Humanity changed again. This culture generated manufacturing and the dominance of nature.

Technology is not a bad thing. But it is interesting how its growth created a material culture that unleashed massive changes on the environment. As Robert Friedel wrote “... the nineteenth-century transportation and communications revolutions spread the idea that improvement was not limited to tools, materials, and other instruments of production, but that the very quality and pace of everyday life could be altered by it ...” [6]. And altered it was.

Culture as an intermediary between people and their environments has the potential to restore Humanity's integration with the Biosphere. When technology created a rampant material culture, people didn't understand their link to the whole of the environment. They saw nature only as a resource to provide what they wanted. They didn't understand the broad impacts of their actions. The adaptive relationship between people and their environment, that their ancestors knew, had been lost. But modern knowledge and communication can help people understand their link to the whole environment.

This new understanding will form part of a new culture to reconnect people with their broader environment. A culture to a) help them understand the importance of “maintaining and restoring the carrying capacity of the Earth” [4] (b) repositioning technology within a new framework, and c) protecting the Biosphere. To quote Friedel again, “Understanding begins with humility and skepticism, but it deepens only with a confident sense that our technologies are the product of human desires and human capabilities, ultimately answerable to our own wills” [6].

This new culture must develop quickly. We can be encouraged by the fact that cultural change and its impacts continue to accelerate. Only 30 years ago, Linus Torvalds initiated the open-source culture when he created the Linux operating system. Open-source has greatly increased the speed of business innovations world-wide. In an even shorter period, smart-phone culture has also changed how people think.

Culture of Sustainability

We need, therefore, to develop a culture of sustainability. With modern communication, we can develop this culture quickly. To achieve Karl Folke's proposed “social-ecological systems in tune with the resilience of the Biosphere” [5].

A culture of sustainability will change fundamental processes in a city. When key stakeholders are aware of the new culture, they will respond in the following ways:

- Governments will put sustainability in all policies and programs
- Businesses will produce more sustainable goods and service
- Funders will support more sustainable technologies

- Organizations will hire more sustainability graduates
- Citizens will practice sustainability in their everyday lives

The new culture will also increase innovations for sustainability. As noted by Mark Pagel, “most inventions meet nothing but indifference, even from experts” [7]. But in a culture of sustainability, a great appetite for those innovations will lead to their acceptance.

We need a new resource to power the development of a culture of sustainability. That resource is human capital – the energy and ideas of people. Every city has it in abundance. Human capital can drive grass roots development of sustainability practices. This can increase sustainability in the poorest cities. It can also complement the top-down approach of planning in wealthier cities.

Because people follow trends and learn from each other, we can be confident that ordinary people will adopt sustainability practices when they see them in others. As Mark Pagel noted “Humans are hyper imitators ... imitating and copying have played an important role in our species’ survival and prosperity” [7]. Therefore, to initiate this new culture in a city we simply need to begin a process of engagement in sustainability.

The Rensselaer Polytechnic Institute, the oldest research university in the USA, had found that when 10% of a population holds firmly to a belief, the rest of the population will follow [8]. So, if we engage 10% of the people in a city in sustainability, this new culture will grow automatically.

Biosphere Eco-City

A model called Biosphere Eco-City (BEC) uses engagement and human capital to build a culture of sustainability. It overlays an urban-centred region to coordinate and share benefits between urban and rural areas. BEC uses simple Themes and Tools to engage people and organizations.

BEC has 10 Themes that represent all the broad areas of direct action for sustainability. They are Transportation, Energy, Design, Habitat, Food, Natural Capital, Waste, Health, Recreation, and Sense of Place. Themes bring together people with common interests, for discussion and action. And because they are concrete, Themes help everyone understand sustainability.

BEC uses five Tools of Engagement. All of them increase understanding, provide opportunities for involvement and innovation, and share information. Because they all further engagement, the choices of when to use each Tool will depend on local preferences and opportunities. The Tools are a) Database of Sustainability Projects, b) Demonstration Projects, c) Sustainability Plans, d) Theme-based Workshops, and e) a Stakeholders Sustainability Council. Examples from Ottawa BEC – which has been testing them since 2009 – illustrate their use, as follows.

The Database of Sustainability Projects provides summaries and contact information of all sustainability projects within the Biosphere Eco-City. Anyone can view projects within their Theme of interest (Energy, Food, Health etc.) to learn what is happening. They can gather ideas to start a project of their own, ask for advice, or offer to support one of the listed projects. Ottawa BEC has hundreds of projects in its database.

Demonstration Projects show methods used to develop sustainability. They are presented in ways that make them easy to understand. Here are two examples. Ottawa BEC developed a self-guided Sustainability Tour of 10 easily accessible sites that illustrate the 10 Themes. Another organization in Ottawa used five Themes to demonstrate how to develop community sustainability projects in urban, suburban, and rural parts of the city.

Sustainability Plans are developed by members of an organization for their own use. Members discuss issues and choose actions to address them, for each of the 10 Themes of Sustainability. The resulting plan contains individual and group projects, from which each member may choose a project to do. Ottawa BEC has supported almost a dozen School or Community Sustainability Plans and is now working on a Business Sustainability Plan.

Theme-based Workshops feature speakers and public discussion on aspects of an individual Theme. Each workshop targets the people interested in that Theme. The experience has been that participants enjoy them. On the Ottawa BEC website (<http://obec-evbo.ca>) there are summaries of workshops on Food, Habitat, Health etc.

The Sustainability Stakeholders Council is an open forum for all organizations interested in sharing ideas and information on sustainability. Ottawa BEC’s stakeholders council began hosting semi-annual forums in 2019, in which discussions of issues lead to project suggestions. Volunteers turn the project ideas into more formal proposals, which may then be taken up by any organizations in the city.

The BEC Themes and Tools of Engagement can all be used in a city that lacks a strong planning system or other formal resources for sustainability. The main resource for sustainable activities in such a city will be human capital, which exists in every city. With BEC, voluntary engagement and cooperation lead to actions for sustainability. BEC Tools do not require government direction.

In a city with good planning and science, with goals for energy, water quality, transportation, waste and so on, there is still a benefit in adding the BEC approach. This will ensure that the valuable resource of human capital will be fully used for transformation. The BEC approach will help individuals, stakeholders, communities, and government to move in parallel towards a truly sustainable city.

Engagement of city residents in city sustainability brings out three qualities in them:

- Commitment – Residents who become engaged through any Theme, will commit to the broader ideas of sustainability too. They will cooperate in carbon reduction and other programs without persuasion.
- Ideas – Anyone can have a good idea. When residents understand that their ideas for sustainability are wanted, innovation can happen at all levels. Imagine the flow of ideas from ordinary people on food management, recreation, child activities, home renovation, equipment use, recycling etc.
- Leadership – Making sustainability grass roots will create a new class of leaders in communities. When they find their area of interest, they will bring together other residents to identify needs, share ideas and act. They'll be proactive in asking for advice from colleges, universities and government staff, so they can continue to lead. Imagine projects springing up all over a city because people in communities want to do them.

Creating a national network of Biosphere Eco-Cities provides another benefit. That of sharing ideas and information among cities to accelerate BEC development. In 2021, BEC Canada was formed to support initiatives in five cities: Ottawa, Toronto, Brampton, Edmonton, and Vancouver. All but Ottawa are in early stages of development but a national secretariat is providing advice and assistance.

Any group interested in trying the BEC approach in their city can view the educational website of BEC Canada (<https://bec-evb.ca>) and request advice and project manuals. They will find that starting a BEC initiative is relatively easy. It can be managed by a non-government organization, a city department, or even an informal group put together for start-up. A first project could be anything coming out of one of the Tools to engage people.

CONCLUSION

Human pressures are changing the Biosphere, and its new form would be less supportive of current species including our own. Efforts to reduce impacts through science, international programs, education, laws, and planning are producing benefits, but not quickly enough and problems are increasing. The only way to maintain and restore the carrying capacity of the Earth is to develop social-ecological systems in tune with the resilience of the Biosphere. Culture is the only mechanism sufficiently comprehensive and adaptable to reconcile human activities with the complexity of the environment. Since the rapid growth of technology led to a material culture, a new culture is needed. A culture of sustainability would answer that need. It could be developed quickly in any city because of several factors: a) cultures can now grow quickly, b) people imitate one another, c) engaging 10% of a population in sustainable activities could lead automatically to adoption of sustainability by the whole population. The Biosphere Eco-City (BEC) approach creates a culture of sustainability through human capital. It is easy to use, low cost and useable in any city. Interested persons anywhere may obtain Information on BEC at <https://bec-evb.ca>.

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CRYPTOURBANOMICS: A METHOD TO BOOST URBAN CIRCULARITY WITH BLOCKCHAIN TECHNOLOGY. USE CASE ON ENERGY TRANSITION

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ABSTRACT

Cryptourbanomics puts forward the idea that there are forces and capital in our society that cannot be dismissed or neglected but that the *System* (understood as *Establishment* or *Statu-quo*) has failed to acknowledge or been unable to address. These social forces have strong ideological, cultural, or identity components, sometimes related to an unrealized Right to the City [1]. The social capital behind those forces are often citizens who gave up -the so called *drop-outs*-, because they lost their faith in the *System* and prefer living in their own world. Blockchain is the technology that empowers these unheard social forces and capital. However, blockchain will remain as an *Anti-System* technology until it finds a fit within the *Establishment*, until the *Statu-quo* acknowledges and ushers it. Cryptourbanomics is a novel method that brings into the blockchain those societal challenges that the *System* leaves unsolved. And because today's societal challenges mostly take place in urban environments, the Cryptourbanomics method focuses on the overall urban sustainability and analyses them with blockchain lens. The Cryptourbanomics method includes an array of blockchain tools to tackle legacy societal challenges yet unsolved by the *System* with a more decentralised, distributed, transparent and neutral approach. This paper shows how the Cryptourbanomics method can help deliver on Urban Sustainability by shifting powers, from the Establishment to Communities, and it showcases this with a use case on energy transition, the so called ioCAT project, a project promoted by ICAEN, the Catalan Institute of Energy that rewards citizens' sustainable actions and use of renewables.

KEYWORDS

blockchain; sustainability; decentralised governance; distributed networks; disruptive citizen-led energy transition

INTRODUCTION

Blockchain technologies can deliver on the promise of a more citizen-centric society since blockchain technologies are bottom-up-led by design and rely on a peer-to-peer network of individuals. Blockchain technology is typically defined as a peer-to-peer decentralised and distributed network of nodes seemingly securing transactions on a largely replicated ledger. Accordingly, a blockchain is disintermediated since users (peers) operate directly with other network users without the need for a middleman or central authority to grant them access. And are precisely these two features of distribution and decentralisation what makes blockchain a disruptive technology. However, methodologies need to be developed to effectively use blockchain technology in real-world situations. Cryptourbanomics offers a method to use blockchain in tackling real-world challenges that the *System* has been unable to solve with traditional legacy mechanisms such as urban strategies, policies, planning, and regulations. Blockchain is still an immature technology and meaningful real-world use cases are scarce, hence the importance of methods like Cryptourbanomics that help its implementation. Although some authors argue that the philosophy that exists around blockchain makes it a mature technology [2], it is widely accepted that blockchain technology is in its infancy, being at the development stage that the web was in 1992, thus with lots of crises and hypes yet to come. In any event, the *System* has not even acknowledged blockchain as a technology. Within the *System*, only a couple of genuine projects are relevant. These are the government-led blockchain platforms of Dubai and Illinois [3]. On the other hand, the *System* is experimenting with the technology by transfiguring and adapting it so that it can be controlled, resulting in the so-called “enterprise blockchain”, which is not actual blockchain but a different technology, that is private and/or permissioned distributed ledgers (DLT).

The Cryptourbanomics method specifically looks at real-world implementations that will solve those legacy societal challenges that traditional mechanisms could not. Traditional codes to tackle societal challenges include strategies, policies, planning, and regulations. The novel findings of the Cryptourbanomics method unveil specific blockchain code that can help deliver traditional codes in a more decentralised, distributed, transparent and disruptive manner. Indeed, blockchain codes such as, transactions, tokens, stakeholder groups, and decentralised autonomous organisations can be paired with traditional codes to tackle those unsolved legacy challenges with a community-based and citizen-centred perspective. Thus, the Cryptourbanomics method can be summarised as a governance model to tackle people’s unsolved challenges by the people and from the people. If a Cryptourbanomics implementation has no involvement from the public and/or private sectors it will be called a “bottom-only” solution whereas, if there is participation from the *System* it will be a “bottom-up” solution. As part of the state-of-the-art of the Cryptourbanomics method, a thorough research has been conducted to find references and concepts close to the Cryptourbanomics pursuit. The closest were the works of Huckle and White [4], where they suggest a utopian-socialist-kind-of community concept where division of classes dissipates. This lack of methods using blockchain makes the Cryptourbanomics contribution even more valuable.

The Cryptourbanomics model

| Blockchain characteristics | Legacy codes | Blockchain code | Cause stage | Implementation effect |
|---------------------------------|---|-----------------|------------------------|-----------------------|
| Disintermediation Devolution | Strategies cellular automata | Transactions | selecting a challenge | self-sufficiency |
| Disruption Diversity | Policies complex systems | Tokens | designing the cause | empowering |
| Distribution Granularity | Planning state machines | Crowd-sales | implementing the cause | managing |
| Decentralisation Levelling | Regulations notational combinatorics | Organisations | governing the cause | self-governance |

Figure 1. Components of the Cryptourbanomics method

The Cryptourbanomics method consists of 4 components, which are briefly outlined in the table shown in Figure 1. Depending on the nature and complexity of the challenge all 4 components might be required or, on the contrary, just the initial ones. The following sections of the paper describe each of the components. Special attention has been placed on showcasing the pairing between the common elements that can be found in legacy codes as well as in blockchain code. These common elements will make possible to align traditional mechanisms with novel blockchain tools and thus tackle real-world challenges differently. The four pairs “legacy codes + blockchain code” are displayed one per row in table 1 in the second and third columns respectively. The

first column of the table shows blockchain characteristics, dully organised in correspondence with the most relevant blockchain tool serving that characteristic (column 3). Finally, fourth and fifth column describe the cause stage that each of the pairs is able to tackle and the resulting effect of implementing such pair. Boxes in the second/third column show an older technology that allows to bridge the connection between legacy codes and blockchain code and thus establish each of the pairings.

DISINTERMEDIATING STRATEGIES WITH A SIMPLE BLOCKCHAIN TRANSACTION: ioCAT WALLETS

Perhaps basic challenges remain unsolved because there is not the right middleman to address them or simply it is not interesting for intermediaries to get them solved. Whatever is the case, the reality is that there are very important and at the same time essential real-world challenges that remain unsolved. Of course, the *System* tried solving these problems with their traditional codes, mostly by implementing a Strategy that sometimes it even evolved towards a Policy, delivered through Planning governed by a Regulations. This is what we could call the “traditional problem-solving chain of codes”. What the different steps in this legacy chain have in common is that their execution is subcontracted to intermediaries with little or no participation from the beneficiary or end user, that is the citizen. Currently, participatory processes in policy drafting, master planning, and in the passing of regulations are limited to, at most, public consultation taking place at the very end of the process. In other words, the citizen is used as validator but not as designer. The author of this paper has largely published about this issue [5, 6, 7]. Wouldn't all these Strategies, Policies, Plans, and Regulations better cover citizens' needs if citizens would be directly involved in the design process? The answer is yes.

Until 2008 the only technology available to include the citizen in the creation process of a given code were consultations and surveys that, unfortunately, take place too late in the process and therefore can only have a validation input. But since 2008 we have blockchain technology, pioneered by Bitcoin. Blockchain technology does not only allow for an active participation of the citizen but empowers the whole Community to tackle challenges by themselves without the need for a central authority (such as the System) to trigger the “problem-solving chain of codes”. The fact that blockchain is a peer-to-peer distributed and decentralised technology allows for the Community to get organised and transact directly, thus it also eliminates the need for middlemen participation. As mentioned earlier, this community-based approach to problem-solving making use of blockchain technology is what under the Cryptourbanomics method is called the “bottom-only” approach. However, if the System is part of the Community, which is the most desirable situation as we will see later in the article, the approach is called “bottom-up”. In this section we will show how a simple blockchain transaction allows for community-led Strategies thanks to blockchain disintermediation capabilities with the ioCAT project, and how this simple blockchain transaction suffices to address the most essential and basic challenges. This simplicity is in stark contrast with the legacy System needing to implement the whole “traditional problem-solving chain of codes” and yet not solving basic challenges.

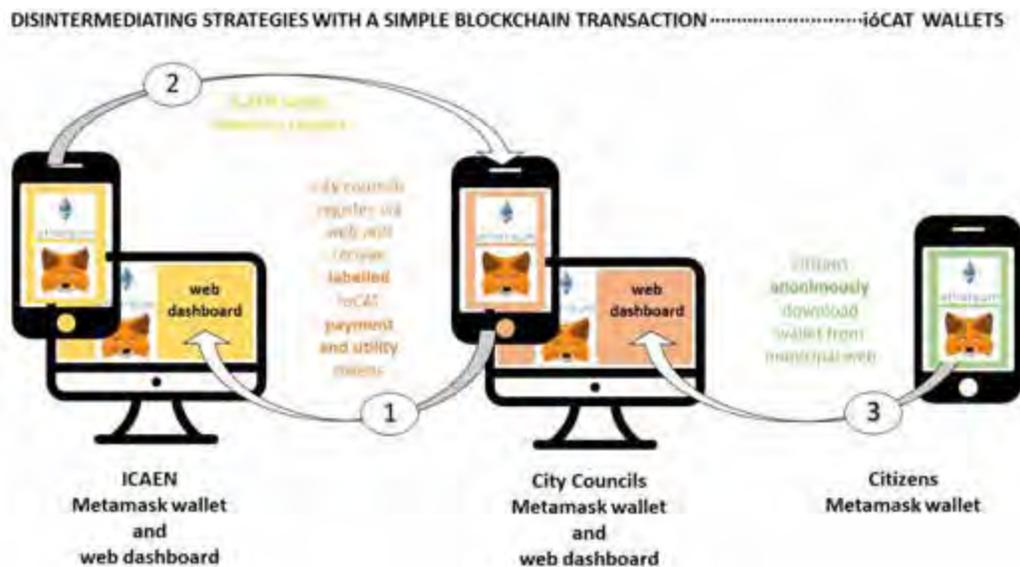


Figure 2: ioCAT wallets

The ioCAT project is included in this paper and it will be used as use case throughout to illustrate the following sections of the method as well. The ioCAT project, promoted by the Catalan Institute of Energy (ICAEN) is an effort to empower communities in being more sustainable and energy efficient by rewarding their actions going in this direction. A project based on the Cryptourbanomics method begins with disintermediation, that is empowering communities to self-solve their challenges and uses blockchain transactions as tool. Sustainability and the shift towards renewables are a global challenge that governments across the world have to tackle locally. The ioCAT project targets sustainability and use of renewables in a bottom-up manner with economic incentives to engaged communities and individuals. As promoter of the ioCAT project, ICAEN sets up a website in which city councils across Catalonia will register (Figure 1). Since the ioCAT project has regional scope, city councils will be the high-level users and interested inhabitants will be the lower-level users. The first point of contact for both, city councils and citizens will be the corresponding *Public Agora Dashboard* in which they will sign up and download their wallets. For the test phase of the ioCAT project, we used the Ehtereum Rinkeby network and Metamask wallets. During the sign-up process of city councils, ICAEN will be receiving a wallet transaction from the sending city council who, in parallel will web contact ICAEN to identify themselves. In return, ICAEN will register that city council and will send a sum of payment, utility and security tokens (Figure 1, step 2), as per what will be described in the next section. HEX data should be enabled in wallets to use the advantages of data field in all transactions. Once the registration of a given city council is complete, they will set up their own web-based *Public Agora Dashboard* in which they will present the ioCAT project at local level and will include guidance on how citizens can set up their own Metamask wallets (Figure 1, step 3). These blockchain transactions are thus the beginning of the whole collaboration between parties and prove to have the desired disintermediating effect as they allow to directly transact without intermediaries or third parties facilitating the service.

DISRUPTIVE POLICIES MADE POSSIBLE WITH TOKENISATION: ioCAT PAYMENT AND UTILITY TOKENS

It is commonly said that blockchain technology is disruptive. Disruption is a consequence of the technology being a disintermediation tool, allowing for peer-to-peer transactions without the need of a third party performing the transaction for us. But, is precisely this disruptive nature of blockchains what causes a lot of misunderstanding around the technology. Middlemen services are afraid about blockchains' disruptive capabilities and, unable to reposition their services in this distributed and decentralised environment they are opting for "pretending" they are embracing the technology when, in reality, they are just using a different technology that is distributed, yes, but not decentralised at all since this would go against their business interests. This non-decentralised version of distributed technologies are the so-called Distributed Ledgers (DLTs). Thus, this means blockchain disruptive capabilities are relevant and it is therefore worth understanding them in full. In this section blockchain disruption will be explained in detail. The blockchain tool acknowledged as having the most disruptive effect are the tokens. The Cryptourbanomics method pairs the tokens with the most disruptive legacy tool within the legacy codes, that is Policies and we will use complex system principles to establish the pairing (see Figure 1). Policies are the instrument within our legacy codes (Strategies, Policies, Planning and Regulations) understood as being the most flexible, creative, capable of introducing innovation and therefore, disruptive.

Disruption in Communities occurs when their species are close to instability. This introduces complexity and evolution in Communities. Therefore, to understand disruption we have to study evolutionary and ecological complex systems, and the modelling of disruption in Communities shows that disruption begins with diversity. Blockchains are certainly not an ecological system but a communications system and, as such, are an evolutionary one. However, some authors sustain that blockchains are not complex systems [8] while others [9] argue they are because are often used to orchestrate ecological systems, as proven by the multiple blockchain applications developed by Communities for Communities we can already find. The Cryptourbanomics method aligns with Albert et al. [10] thesis and affirms blockchains are complex systems, not because of their ecology, but because of their evolutionary nature. Complex systems are in constant exchange with the outside and thus are under permanent disruption but naturally seeking equilibrium. As for blockchains, lacked from ecology and nature laws, were born with an anti-disruption system to stay in equilibrium, the so called consensus algorithms. Therefore, we can affirm that blockchains cause external disruption, like all complex systems do, but cannot be internally disrupted.

Blockchains cause external entropy and thus disruption but they cannot hold internal entropy, hence the existence of consensus algorithms, to pay the cybernesis costs of avoiding internal disruption. But, since physical environments, such as cities, are complex systems as well (of ecological type) and will therefore have their disruption territorialised,

how disruption caused by a blockchain (non-ecological type) in such environment will affect territorialisation? Will it have an incremental disruptive effect? Will it counterbalance territorial disruption and even it out to zero? We can learn the outcomes with the ioCAT use case.

DISRUPTIVE POLICIES MADE POSSIBLE WITH TOKENISATIONioCAT PAYMENT and UTILITY TOKENS

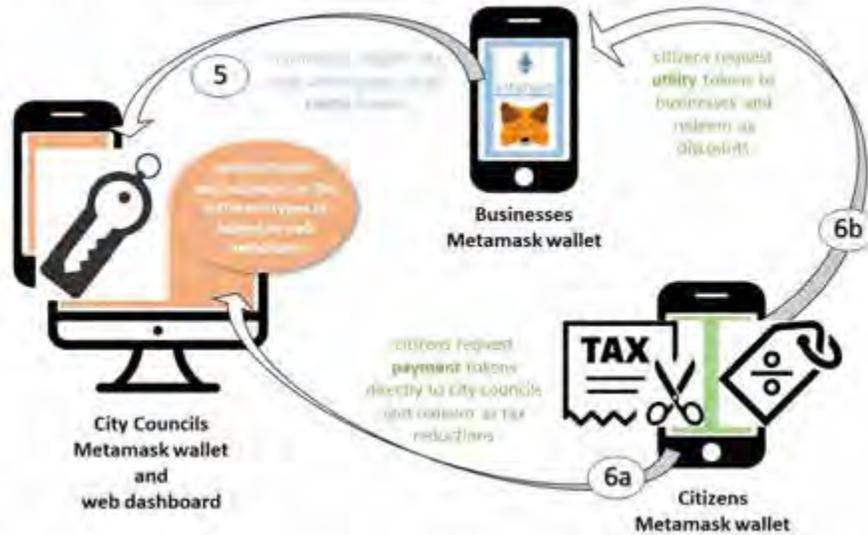


Figure 3: ioCAT payment and utility tokens

The territorialisation of blockchain projects occurs through tokenisation since the connection between on-chain participants and their off-chain location is made with where and when tokens are transacted. We will continue using the ioCAT project as use case to illustrate how the Cryptourbanomics method allows for disruptive policies through tokenisation and how it is territorialised. At this point we have a given municipality and interested citizens sat up with their wallets. Only municipal wallets have received tokens from ICAEN to promote the local sustainable and energy efficient actions they want to reward. These actions will be the policies causing disruption at a given local level. And because tokens serve a specific territorial policy, we speak about token territorialisation. The way this actually occurs within the ioCAT project is by labelling the tokens ICAEN sends to each municipality so that they can only be used locally. This ensures only citizens from a given municipality will be using tokens within the boundaries of their municipal territory. City councils will publish in their *Public Agora Dashboard* the equivalences for the different types of tokens. The payment token is meant to reward citizens for sustainable actions such as recycling, attending courses on energy transition, participating in collective actions to clean parks or other environmental resources, etc. All these activities can be either on-line or on-site and will be always promoted by the city council. The exchange of tokens will be offered as tax reductions or discounts in municipal services (Figure 3, step 6a). The utility token is meant to help boost local economy of businesses offering sustainable and energy efficient services and products. Interested businesses will sign up as high-level users within the local *Public Agora Dashboard* meaning that, while getting their wallets, they will also web-contact the city council introducing themselves and proving they qualify to receive utility tokens (Figure 3, step 5).

For the city council to decide whether a certain business qualifies to receive tokens, they will have to present the catalogue of products and services they want to promote and for which they assign token compensation. The municipality will have the discretion to assume the cost attached to these compensations up to a certain amount or delegate the economic burden to businesses themselves with the reason being that because sales will increase thanks to the promotions, these will compensate for the economic loss. In any event, the municipality provides the surveillance for the right businesses and products to join. Once businesses have the requested utility tokens in their wallets, they will send them to their clients once they purchase a product or service from the agreed catalogue (Figure 3, step 6b). Because blockchain notarises everything, it will be possible to trace any businesses and monitor their commercial token activity at any time. At this point it is worth mentioning that the ioCAT project is aware that only city councils of a certain size are able to organise payment token actions as well as have critical mass of businesses related to sustainability and energy transition. In this regard, territorial cooperation will be implemented so that citizens of small towns can attend payment token activities and experience sustainable shopping in nearby cities. In the ioCAT application of the Cryptourbanomics method, both the payment and utility tokens are the territorialisation mechanism to establish the actual connection between the on-chain and off-chain elements (population and their environment) showcasing blockchain's socially embedded features and proving blockchain's disruptive capabilities. Blockchain's socially embedded features are key for the next functionality of the Cryptourbanomics method, custodian distribution.

DISTRIBUTED PLANNING RELIES ON STAKEHOLDER CUSTODY FOR A GRANULAR IMPLEMENTATION OF DISRUPTIVE POLICIES: THE ioCAT SAFE AND ITS SECURITY TOKEN

It might be already clear, from the two sections already studied, that the Cryptourbanomics method builds on the previous component of the method. This is because both, blockchain code and traditional codes do. Therefore, Disruptive Policies and their tools take on Disintermediated Strategies and build on their instruments. This cumulative effect will become more evident in this third stage of the method, where Planning builds on Policies. So far, we have seen how blockchains can be Disintermediated thanks to Tx's cellular automata behaviour [11]. Regarding Disruption, blockchains can cause it because they are complex systems [10]. And, concerning Distribution, how do blockchains behave? Like state machines. According to Saito and Yamada [12] blockchain infrastructure is considered a state machine since it consists of a network to distribute and manage state transitions. A general definition of a state machine is that of a technology that manages and distributes transitions towards a physical stage. A vending machine is a good example of a state machine, it allows users to transit from a physical state 0 (eg. *without coffee*) to a physical state 1 (eg. *with coffee* in their hands): when you insert the coin, you will move from state 0 to state 1. Further on state machines, these can be infinite or finite. A computer is a finite state machine since it can only be on or off, whereas a vending machine is non-finite since it can be off or on but, within the on state, it gives you a wide range of physical outcomes / products, meaning it has multiple on states. It is important to highlight that whether a state machine is finite or infinite, the change of state involves physical elements (the vending machine will give you a physical product, the computer will heat up when on, etc.). The same authors [12] define blockchain technology as an infinite state machine that uses consensus methods to agree on each new state of the distributed peer-to-peer network, that is, the longest chain will decide on the new state of the blockchain machine. Scalable granular distribution -either through sharding, side chains or payment channels-, is key to blockchain resilience since it ensures no single point of failure at present and in future stages of network growth.



Figure 4: ioCAT safe and its security token

Cities are state machines too, and of infinite type. Change of state is produced with the implementation of urban master planning and it results in new developments or new zoning layouts. Master planning can guarantee the resilience of cities with a scalable granular distribution of elements -through fractality, multi-scalability and polycentrism of projects- it will ensure continuous operation in cities even when new developments are added. And resilience is not only virtual or physical, as a result of the granular distribution of elements being part of the network (e.g nodes in a blockchain or power stations in a city), it will also have social, economic and environmental resilient benefits. For example, the more distributed economic activity is in cities, the better options are given to entrepreneurs and businesses to succeed. And this will have a positive impact in society, improving economic and social resilience as well. There is an interesting debate on whether the best physical expression of granular and scalable distributed

urban systems are more like Paris and less like Brasilia. In author's opinion, the ideal layout is somewhere in between, like in Cerdà's Barcelona. Over planned cities such as Brasilia do not scale well as it is difficult to include fractality, multi-scalability and polycentrism in their locked-in masterplan designs. On the other hand, organically planned cities like Paris or London do not scale well either since the lack of pattern makes it difficult to include fractality, multi-scalability and polycentrism in a consistent and harmonic way. The growth of cities tends to speed up even as population increases because of network effects. The same is true for blockchain networks, the larger and more robust the community, the more valuable the crypto network. The way you architect a successful city and the way you architect a successful network are very similar. In summary, both blockchains and urban planning tools are state machines of infinite type. Their infinite outcomes translate into a granular scalable effect. This allows for direct implementation of blockchain distribution tools in a physical support, resulting in the territorialisation of blockchain tools and therefore a fine grain scalable implementation of Disruptive Polices.

Back to our use case on the ioCAT project to illustrate what has been just described. Granularity of the distributed physical implementation for the payment and utility token rewarding sustainable actions is quite straight forward since it will happen naturally across the city at individual level. A different thing is the implementation of the policies to disrupt energy production, that is empowering citizens to become energy sufficient with the installation of domestic solar panels. This policy will not occur naturally like happening with sustainable actions simply because it requires investment and it is therefore not accessible to everyone. In order to improve accessibility to this policy, a granular funding vehicle will be put in place. Granularity will take into consideration level of income, providing higher subsidies to lower income households. Like in the implementation of sustainable policies, the self-sufficiency policy requires from a dedicated token. Differently from the payment and utility tokens, respectively used for direct payment of taxes and as a discount service in businesses, the token here has to hold and release value once the renewable energy projects are completed. It is worth mentioning here that all tokens have been designed under the ERC-20 standard and deployed on Rinkeby using the Remix injected web3 facility. Tokens holding and releasing value once certain conditions are met are typically named security tokens.

The ioCAT security token works as follows: A household interested in having a domestic solar installation will request security tokens to their municipality to benefit from subsidies (Figure 4, step 7). This request will be off-chain and be made using the municipal web dashboard. City council will analyse the request and award a certain number of tokens depending on requester's income. City council will create a blockchain safe and deposit the tokens there which will be released into requester's wallet at project completion. Requester will be invited to join the safe as well as the engineer who will perform the installation (Figure 4, step 8). Both requester and technician will receive invitations to their wallets to join the safe. We used the Rinkeby Gnosis Safe as it directly connects with Metamask wallets. Once the installation is completed the technician will sign off the token transaction (Figure 4, step 9). By signing off the transaction the engineer is at the same certifying that the installation dully meets the requirements to benefit from subsidies. Next, the requester will sign off the token transaction and by doing so it certifies that the installation has been dully registered in the official listings. Lastly, the city council -without the need to review on-site the whole process- thanks to the real time auditing made possible by all this blockchain transactions, will sign off the transaction and release the tokens, which will go to the requester's wallet (Figure 4, step 10). The requester will pay the engineer in fiat and in tokens for the installation and the engineer will then claim the value of the tokens to the local council. With the use of a safe we ensure no fraud is possible thanks to the multisignature procedure as well as avoiding any on-site inspections thanks to real-time notarisation of all changes of state during project implementation. Moreover, a fair distribution of the energy policy is ensured with the use of granular security tokens with different value in relation to local factors.

PEOPLE'S-DELEGATED REGULATIONS CAN BE ACHIEVED WITH GOVERNANCE RAN AS A DECENTRALISED ORGANISATION: ioCAT DAOs

As mentioned in the introduction, blockchain is the technology that can provide answers to causes and challenges unheard or unaddressed by the *System*. The set of blockchain tools we have seen in previous sections enable the implementation of more citizen-centred legacy codes, that is Strategies, Policies and Planning. This section showcases the benefits of pairing the most sophisticated blockchain tool, Decentralised Autonomous Organisations (DAOs) with the most complex legacy code, Regulations, so that challenges can be Decentralised and governed by citizens. A DAO is a fully automated organisation that exists only in code but performs all actions a traditional or legacy organisation would do such as contracting providers, delivering projects and proposals, paying salaries, taking business decisions, etc. The main difference is that, in a DAO, organisation participants are represented via their accounts and they can delegate their decision-making tasks to other participants making

use of a blockchain protocol called Liquid Democracy. Another important characteristic of DAOs is their democratic modus operandi, which implies all decisions are voted and have to be consensued. DAOs can be set up by anyone willing to tackle a cause remaining unsolved or not properly addressed by the system. Therefore DAOs are a promising, people-centered, alternative to traditional forms of governance.

The blockchain tools developing decentralised governance are Blockchain Congress and Liquid Democracy. The later is a powerful delegation instrument which expresses in two forms, House of Representatives and the Executive Branch, with incremental use of delegated powers respectively. Blockchain Liquid Democracy can help cities become more decentralised and city planners and policy makers should plan for the introduction of those instruments to build a true participatory democratic society. In previous sections we learned that the Disruptive behaviour of blockchains is due to their complex system nature [8] and that their Distributed nature is because blockchains are infinite state machines [12]. When it comes to Decentralisation, we will learn that the lack of a central authority and its replacement by a blockchain-based democratic organisation is possible because of their embedded notational combinatory logic [13]. Combinatory logic is a notation to eliminate the need for quantified variables in mathematical logic. It is based on combinators, a higher-order function that uses only function applications and earlier defined combinators to elaborate a result from its arguments.

Blockchains' notational combinatory logic is what makes the technology socially embedded [13] and, therefore, delegated, and this allows for physical civil intervention on issues that are typically deemed within the powers of state and institutions [14]. In total agreement with these authors, this presentation of the Cryptourbanomics method concludes that blockchain technology empowers citizens to self-address and self-manage challenges that the *System* has been unable to solve by giving them the digital tools to transform the traditional legacy mechanisms into citizen-led instruments. Indeed blockchain opens the possibility to new contractual options that will be worth exploring [15]. And, since blockchain allows for civil intervention on issues that are typically deemed within the powers of state and institutions, citizens will become the new intermediaries, able to empower civil society to run local public goods and services and facilitate economic and social entrepreneurship [16].



Figure 5: ioCAT DAOs

For example, in the ioCAT project use case, the DAO could be formed by the members of a group of households in the same building who want to implement a shared solar installation in the common roof. This would be a membership-type DAO in which decisions would be taken, for instance, per ownership stake of such installation. We chose the off-the-shelf Membership DAO for Rinkeby from Aragon to conduct some tests and it proves to be optimal for the Metamask wallet. Once decisions are taken using this facility tool, the representative of the community would follow the procedure established in the previous section to claim the subsidies for the solar installation in behalf of the community (Figure 5, steps 11 to 14). Finally, as per the Cryptourbanomics method design, community members would close the DAO facility once the cause is deemed solved, in this case the cause is the installation of a solar roof.

CONCLUSIONS

Cryptourbanomics is a response to failed attempts to deliver on Urban Sustainability, the most recent example of this being Smart Cities initiatives. Cryptourbanomics begins by acknowledging the need for addressing causes that the System has been unable to solve, as important as Urban Sustainability. And, since blockchain is yet an anti-System technology, it is best placed to tackle those. But, once blockchain technology will be endorsed by the System, Cryptourbanomics will still remain relevant since its methodology consists of providing the missing connections that will allow for an effective use of blockchains in the physical world, for instance, in urban environments. Therefore, and since the Cryptourbanomics method ultimately aims to give response to Urban Sustainability, it provides the virtual-physical link for the three pillars of Urban Sustainability, social, economic and environmental. As seen with the cause used throughout the article as example, the ioCAT project, social sustainability is achieved by linking blockchain's decentralised governance capabilities with a bottom-up physical DAO as decision-making mechanism. Regarding economic sustainability, blockchain's distributed functionalities are used to physically implement the governance by creating a web dashboard to allocate and assign roles to solve the cause and its sub-causes. Lastly, these two elements of social decentralisation and economic distribution result in a third notation, that of disruptive ecology. In the ecological sustainability pillar, communities are maintained in their environments with the ioCAT tokens, as a means to fix communities in their environments by introducing economic diversification and complexity through complimentary currencies. Throughout the example of the ioCAT project, Cryptourbanomics approach has demonstrated to be solvent in the three areas of Urban Sustainability, proving to be a trustworthy tool, not only for communities willing to tackle causes by themselves but for governments and private sector willing to finally address their long-lasting unsolved challenges.

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SUSTAINABLE SMART CITIES STRATEGIES AND COVID-19: CAN SMART CITIES BE RESILIENT TO HEALTH ISSUES?

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ABSTRACT

This paper analyzes smart cities according to their strategies to be resilient to health issues, integrating to this analysis more data on health than in previous studies. It complements previous analyses of global smart city strategies classically defined in seven dimensions. The article also proposes a methodology for focusing on certain aspects of a smart city and highlighting specific points of their strategy. In a first study, we previously showed that three different smart city strategies in Europe were developed and underlined that there is no single type of smart city. They have different strategies according to their own urban and economic development. In the study presented in this article, we understand how smart cities can be relevant to respond not only to environmental challenges but also to develop a more global resilience capacity, notably in the face of health risks such as the COVID-19 pandemic, but also more broadly, to urban health issues. The proposed health dimension will thus complement the analysis of the seven dimensions of smart cities and characterize the health resilience capacity. This exploratory classification reinforces the relevance of the dynamics' capabilities approach of understanding smart cities. The classification shows the robustness of this new smart health dimension in the smart city model.

KEYWORDS

Sustainable Smart Cities; Resilience; Smart Health; Dynamic Capabilities; Principal Component Analysis

INTRODUCTION

The World Health Organisation defines health, in the preamble to its constitution, as a “state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” [1]. Thus, by this definition, health is considered as a global state which includes many factors, known as determinants of health. These determinants include the social and the economic environment, the physical environment, and the individual characteristics and behaviors of people. In this context, urbanization is a factor which impacts health and some evidence of this has been published on “urban housing, environmental and non-communicable diseases, communicable diseases, road trauma, psychosocial disorders, sustainable urban development, urban wastes and health services” [2]. Thus, the emerging concept of urban health appears to be relevant to understand how the social and physical environment in which human beings live, as the urban resource infrastructure and the built environment, can influence their quality of life, wellbeing and finally may affect their health [3,4]. The COVID-19 pandemic revealed the interaction between health issues and urban areas concerning environmental quality, socio-economic impacts, management and governance, transportation and urban design [5]. This health crisis leads us to question the capacity of cities to respond to an epidemic, specifically in the context of increasing data creation and sharing [6].

This question is relevant in the context of smart cities; indeed, the concept of the smart city was born out of a desire to propose a development and management of cities that considers the challenges they face, including the increase in urban growth and its environmental consequences. Smart cities are generally defined as cities that use technological tools to meet a particular need and make the city smarter [7], but the concept must be more global, understanding technological tools as a means and not as an end point [8]. For this purpose, the theoretical framework proposed by knowledge management is relevant and since 2012, it has been increasingly used to analyze smart cities [9]. In this approach, smart cities are seen as organizations having central capabilities that are the source of their smart strategy. In this context, the seven dimensions characterizing smart cities - smart architecture and technology, smart citizens, smart economy, smart environment, smart governance, smart living and smart mobility [10–13] - are considered as central capabilities that smart cities must develop.

In a first study [14], we demonstrated that there was not a smart strategy implementing the seven dimensions in an equitable manner but three smart strategies, showing that all smart cities did not have the same level of development in the seven dimensions. This first study also highlights that the health dimension, classically considered as a sub-dimension of the living dimension, was not precise enough to try to understand the notion of urban health when cities face a real issue, such as the COVID-19 crisis.

This article aims to propose a theoretical development allowing to overcome this limit, by creating an eighth “health” dimension. This eighth dimension tends to appear in many scientific studies [15] but these studies are mainly interested in the technological aspect of the health dimension. Through the creation of this new variable, we want to understand the notion of the overall urban health of a city since we are going to analyze this dimension regarding the seven other dimensions, thus taking into account all of the elements of global health of the WHO. Combined with data on COVID-19, this will also give an analytical reading grid of the resilience of cities in the face of a health crisis.

METHODS

In our previous study [14], we analyzed the smart city strategies of 40 European cities highlighted by different classifications and indexes as smart. Briefly, the objective was to understand the different strategies of smart cities considering that there is not one type of smart city but different ways to achieve the sustainability of cities. We collected seventy-nine variables to characterize the seven smart dimensions and six variables to describe the socio-demographic aspects of cities, from Eurostat Digital Economy and Society Survey, Open Street Map (OSM), World Bank Open Data, OECD, and the UN. We performed a Principal Component Analysis (PCA) for each of the seven smart dimensions, considering each principal component as core capabilities, and a Hierarchical Ascending Classification (HAC) based on the principal components in order to group the cities according to their common characteristics, forming three clusters (Figure 1). Finally, we highlighted three main strategies according to the clusters found: an emerging smart strategy, a technology-oriented smart strategy and a sustainable smart strategy focused on the inhabitants. The first class presents issues of air pollution, but also smart solutions to promote various types of mobility. The second class develops strategies focused on technology, e-commerce, e-citizenship, equipment and infrastructure, and digital accessibility, all of which are central to the smart city approach. The third class brings together strategies focused on quality of life, information, energy, the environment, entrepreneurship, sharing platforms, in addition to transport issues in the face of car dependency. These are cities with clearly defined environmental objectives. Based on this first work, we completed our analysis to particularly focus on health resilience in smart cities.

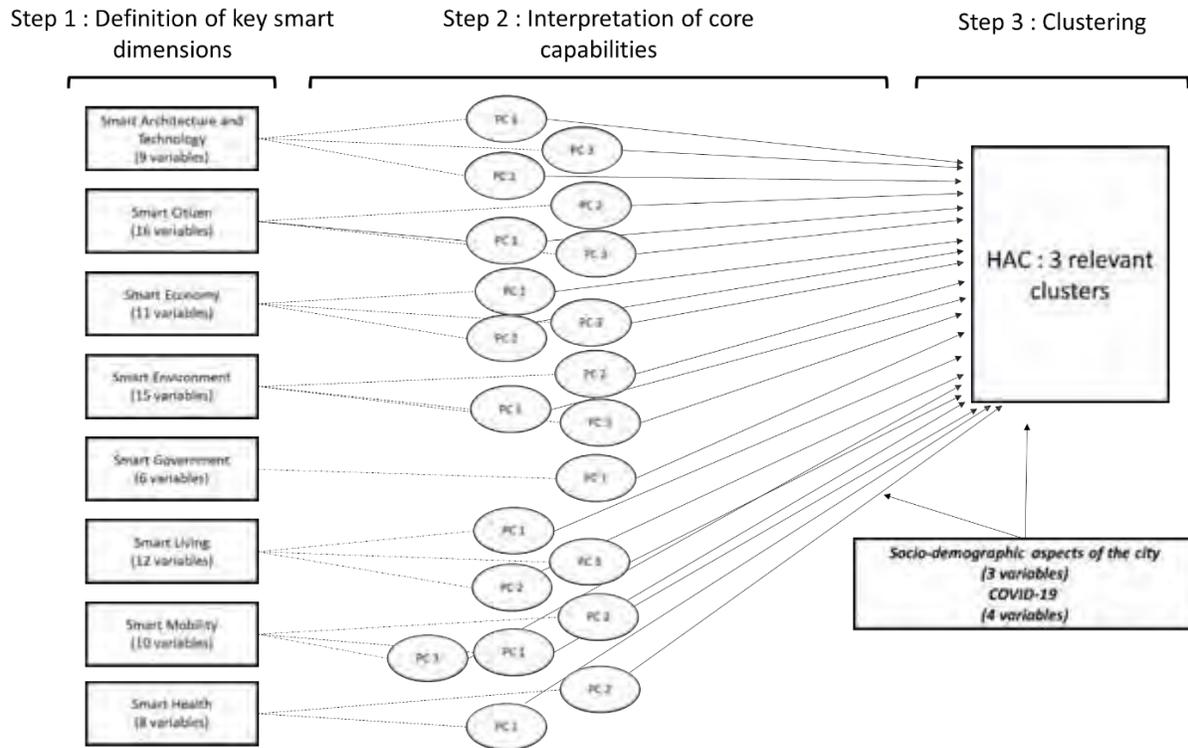


Figure 1. Methodology for clustering sustainable smart cities including smart health. Source: authors

Creation of the Smart Health Dimension

The construction of this new dimension is based on the variables that were previously retained in the health sub-dimension of the classic analysis of smart cities. Then, in order to create the smart health dimension, we collected data from OSM on basic health infrastructure such as clinics, hospitals, health centers, on health specialties infrastructure and on alternative medicine. To improve the precision of this variable we have collected new data. First, we also included health proximity infrastructure such as pharmacies, dentists and therapists. The extraction of this information from OSM allows quantifying the availability of infrastructure per cities. Secondly, we collected information from Eurostat. The key indicator of e-health produced by this statistical organization gives us information on the use of the internet for health information and for health appointments by country. Then, we use the indicator of healthy life years per country, which “measures the number of remaining years that a person of specific age is expected to live without any severe or moderate health problems” [16] as an indicator of quality of life and life expectancy and we collected the number of people over 65 years old in each NUTS2. Finally, nine variables explore the smart health dimension of which five are collected at the city scale and three others are national information (Appendix Table I).

Statistical Analysis

The data collection includes for all eight dimensions of our analysis of smart cities a total of 87 variables and 3 variables describing the socio-demographic aspects of cities: the number of inhabitants, the population density and the gross domestic product by city. To put into perspective these data with the actual COVID-19 pandemic, we collected information from the European Centre for Disease Prevention and Control, on the number of COVID-19 cases and deaths per country and the number of the first dose and of second dose vaccinations.

To analyze these dimensions, we performed a PCA for each smart dimension and we systematically retained the axes that explain at least 55% of the variance or the first three axes. We also included socio-economic variables describing the cities in the eighth PCA. Finally, we carry out the clustering by a HAC of the eight smart dimensions.

RESULTS

We examined European cities per key smart dimensions to identify the core capabilities (Figure 1) following the seven smart dimensions identified by Ismagilova et al. [12] and adding the smart health dimension. Each principal component (PC) integrated sociodemographic aspects of the cities and COVID-19 information as supplementary variables. The PC analysis allowed us to define the core capabilities' variables and then to conduct the HAC. Table I shows these results, and two points are important: the evolution of the smart living dimension and the creation of two central capabilities for the smart health dimension. After these two main points of the factorial analysis, the results of the HAC will be detailed.

Evolution of the Living Dimension

In our first study [14], health issues were analyzed by the variable “medical,” which included the number of clinics, pharmacies, doctors' offices, dentists, healthcare centers, hospitals and laboratories in the city per inhabitant. We also added inside the variable “kids” the number of childcare centers. These variables contribute to the core capability of life quality as well as other variables like the number of schools, amenities for kids, place for religious activities, or food services. Therefore, the contribution of health concerns was drowned in the service package of a city.

In the present study, we have extracted “medical” and modified “kids” variables in order to create the health dimension, but this has not changed the structure of the life quality as the main core capability of the smart living dimension (Table I).

Table I. Principal component analysis by smart city dimension and smart health.

| Smart city dimension | PCA results (% of variance) ¹ | Core capability variables – main axes | Interpretation of core capabilities |
|-----------------------------------|---|---|--|
| smart architecture and technology | axis 1 (27.88%) axis 2 (22.97%) axis 3 (14.55%) | A1_energy A2_equip_infra A3_on-line_access | energy equipment and infrastructure on-line accessibility |
| smart citizens | axis 1 (42.42%) axis 2 (14.87%) axis 3 (10.23%) | C1_e-citizen C2_info C3_sharing | e-citizen information sharing trends |
| smart economy | axis 1 (26.38%) axis 2 (20.27%) axis 3 (14.02%) | Ec1_e-commerce Ec2_business Ec3_openness | e-commerce business environment economic openness |
| smart environment | axis 1 (20.83%) axis 2 (17.74%) axis 3 (13.99%) | En1_air_pollution En2_revegetation En3_green_transition | air pollution revegetation green transition |
| smart government | axis 1 (61.73%) | G1_e-government | e-government |
| smart living | axis 1 (39.61%) axis 2 (14.89%) axis 3 (12.42%) | L1_life_quality L2_life_cost L3_heritage | life quality life cost heritage |
| smart mobility | axis 1 (37.07%) axis 2 (22.09%) axis 3 (11.17%) | M1_car_use M2_metro M3_modalities | car use and alternatives metro infrastructure transport modalities |
| smart health | axis 1 (38.10%) axis 2 (19.17%) | H1_infrastructure H2_ehealth | health infrastructure e-Health |

Source: authors.

Interpretation of the Smart Health Dimension

The smart health dimension highlighted two principal components that explain 57.27% of the variance (Figure 2). The first one concerned the health infrastructure (H1_infrastructure) existing in the cities of our panel, explaining 38.1% of the variance and revealing the role of medical offer and proximity. This axis highlights the European cities which offer the most medical and paramedical services to the inhabitants. Although the city which contributes the most to this axis is Berlin, it is not only a question of large European metropolises since Vienna and Hamburg also contribute strongly. Conversely, cities like Rotterdam,

Paris or Brussels do not contribute to this axis.

The second component (H2_ehealth) represents 19.17% of the variance and shows the impact of the use of the internet to search health information and health appointments. These two data are opposed in this axis to the ageing variable. We can also observe in the e-Health axis the opposition between using ICT for managing its own health and the 4 COVID-19 variables. The city of Helsinki contributes the most to the e-health axis in contrast to the city of Milan.

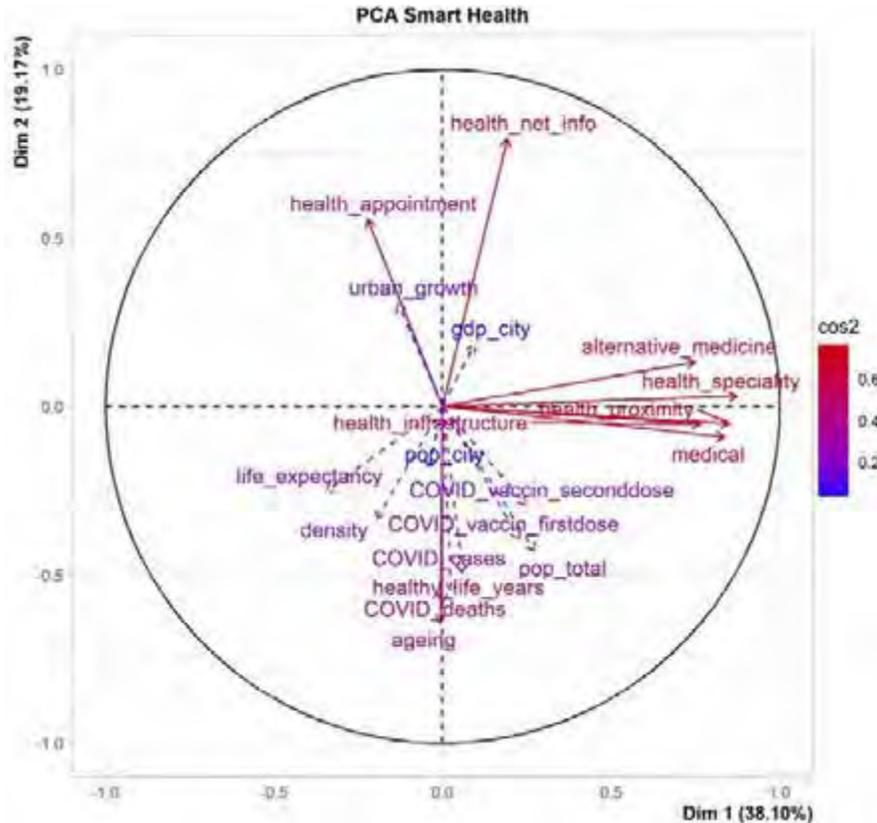


Figure 2. Variables of smart health. Source: authors.

Clustering of Smart Cities

The HAC highlighted three classes of smart cities, the key figures of each class can be found in Table II and their spatial distribution in Figure 3.

The first class has been named as “Proactive smart city.” These cities are engaged in a smart strategy based on the e-health dimension and green transition. The specificity of this class compared to the other two lies in the low values for COVID-19 cases, deaths and vaccinations, showing that by their organization, these cities were proactive facing the pandemic. These cities are mainly located in Northern and Central Europe, with less population and less population density. The paragons of this class are Stockholm, Wien, Copenhagen, Praha and Athens.

This second class, named “Developing resilient city”, shows high values on the COVID-19 death and cases with a low value on e-health, e-government and e-citizen data. Thus, these cities appear to be the least resilient, the smart infrastructure has not allowed strong resilience to the health crisis. These cities are mainly in France, Italy and Spain, with the highest population density of our sample. Roma, Napoli, Milan, Torino and Lyon are the paragons of this second class.

The third class is called “Reactive smart city.” These cities show a high value on the number of cases and deaths of COVID-19 but also on vaccinations, health infrastructure, the citizen commitment and mobility dimensions. Thus, these cities have been able to use their smart infrastructure to meet the challenges of the health crisis. These cities are in Germany and in the United Kingdom. This class is illustrated by Hamburg, Munich, Stuttgart, Frankfurt, Berlin as the main paragons.

Table II. Main core capabilities by cluster.

| Cluster | Core Dimension | Mean Population | Mean Density | Mean COVID-19 Cases / Deaths* |
|---|--|-----------------|--------------|-------------------------------|
| Cluster 1 - Proactive smart city | COVID cases and deaths (-) e-Health (+) Green transition (+) | 1.979.227 | 596 | 464.478 / 9.011 |
| Cluster 2 - Developing resilient smart city | COVID cases and deaths (+) e-Health (-) | 3.982.309 | 1.065 | 3.101.633 / 83.373 |
| Cluster 3 - Reactive smart city | COVID cases and deaths (+) COVID vaccines (+) Health infrastructure (+) Citizen (+) Mobility (+) | 3.630.250 | 852 | 2.918.746 / 84.909 |

Source: authors. *Data extracted 8th July 2021.

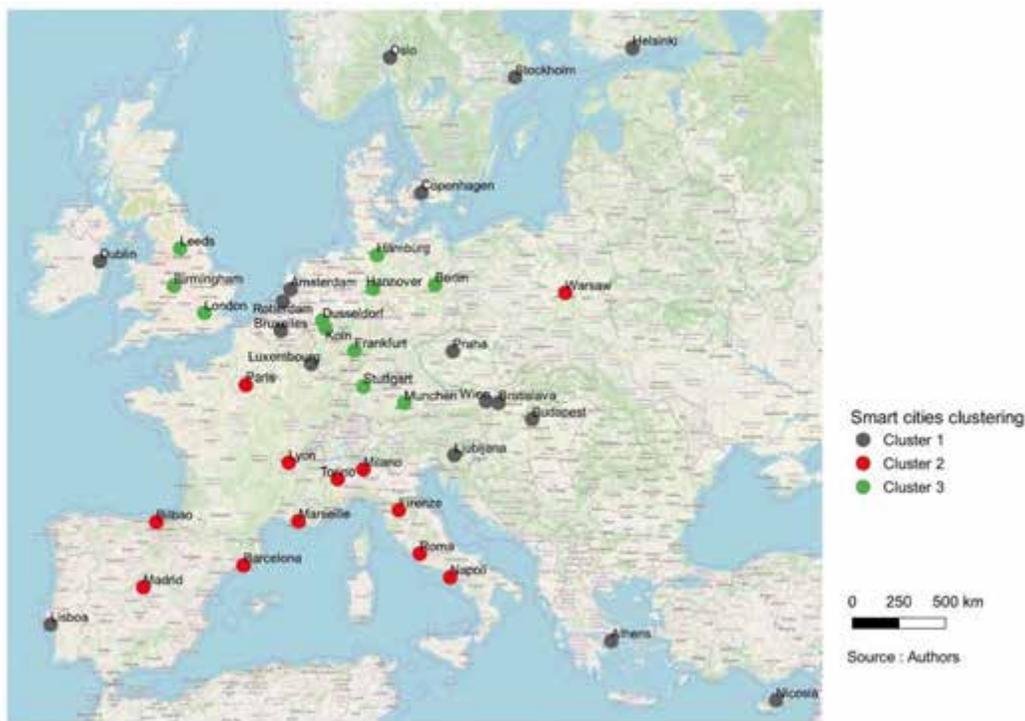


Figure 3. Smart city classification including smart health. Source: authors.

DISCUSSION

With this study, we propose a framework to analyze the capacity for a smart city to be resilient to health issues. We presented an eighth dimension to specifically consider smart health as one of the categories to define smart cities. Our results lead to two main points of discussion. The first concerns the relevance of adding this eighth health dimension in the analysis of smart cities and the second questions the resilience of cities in the face of a health crisis.

The Principal Component Analysis allowed us to identify two axes. Axis 1 highlights that the level of access to health infrastructure is not equivalent in European cities and that the size of this offer is not positively correlated with the size of the cities. A study from the European Commission [17] shows the remaining inequalities in access to healthcare including access to infrastructure and demographical and socioeconomic situations. This shows the relevance of creating the eighth dimension.

With the results of the axis 2, we can observe that some European cities have developed e-health tools, and these are being used, such as in Helsinki, which had already developed tools before the COVID-19 crisis. Since the beginning of the 2000s, e-health networks were developed to organize the healthcare system [18] creating an ecosystem of tools and projects allowing, for example, to better manage care for diabetics [19] or to organize the management of kidney transplants throughout Helsinki but also for the whole country [20]. The implementation of these tools can be beneficial at the time of the pandemic, as people are used to having to use them. For example, in Finland, the Omaolo website (<https://www.omaolo.fi/>) works with the Helsinki government (<https://www.hel.fi/sote/en/services/electronic/>) to propose coronavirus managing applications. Also, the opposition between e-health tools and the healthy life years suggests that these tools can participate as elements of prevention and global health tools, and therefore of better management of a health crisis to improve coordination, communication, education and care [21]. Finally, the opposition revealed between the variables characterizing e-health and the variable ageing raises the question of the appropriation of the technological tools on which the development of the smart city is classically based. Even if an increasing use of e-health and m-health tools is noted in the US in population older than 50 years old as the supports have evolved [22], still sociodemographic barriers remained. The cities around the Mediterranean with a more ageing population may explain why these cities are mainly found in class 2, the class of cities that develop resilience strategies. This opposition can certainly be explained by a structural effect of age class in the population.

These two axes allow understanding of the three identified classes. Cities in class 2 show that the smart label has not necessarily made a strategy for responding to the health crisis possible. These cities are therefore identified as smart cities which are developing a strategy of resilience to health crises on the two axes of the health dimension. Cities in class 1 have apparently been more proactive and this corresponds to strong values on the e-health dimension as well as on green transition. In this class the mean population and the mean density of the population were below the means of the two other classes, which may suggest that they are thus better able to adapt quickly. Class 3 cities were able to react to the crisis apparently by mobilizing health infrastructure, which is more present than in the rest of the sample. Thus, a city developing on the two axes of the smart health dimension could be considered as resilient to health issues.

The present study enforces the place of health concerns in the city with the smart health dimension and new variables particularly on health infrastructure, specialties, general medicine, alternative healthcare centers and vulnerability for ageing and healthy life. COVID-19 variables include the number of cases, number of deaths and vaccination per country. This new study improved our first results [14] and request integrated approach in response to the health crisis at the city level. This statement supports the evaluation made by the OECD [23] which noted the importance of health resilience to be interconnected with economy and political decisions and to be able to propose tools to manage a health crisis.

In the first class, we can also see that environment and health variables were two major core dimensions bringing together the idea of a better capacity to propose a concept of smart city grouping issues on health and on sustainability. This dynamic can also be interpreted in terms of the potential of a city to adopt the concept of urban health as part of its development and to focus on the relation between environment and health. To go further on this interpretation, it would be relevant to mobilize data specific to cities in terms of the health of inhabitants: in particular chronic diseases at the city level. Based on these data, it would be possible to better analyze the notion of the global health of cities, through the intersection of the health dimension with the environmental dimension. The difficulty lies mainly in the fact that health data are managed in most of the European countries by central administrations and the access is uneven and can be complicated for reasons of confidentiality.

Thus, the first limit of our work about the eighth dimension lies in the level of analysis of the variables relating to the e-health axis. Indeed, this axis is supported by many national variables and not specific to cities. However, this limit also appears to reveal the way in which cities act which are constrained by national directives. The second limits identified lies in the choice of the sample. Many cities declare themselves smart without being recognized in the international rankings used in this article. Thus, smaller cities, such as Dijon in France [24], were not included in the analysis while they are developing interesting technological solutions to respond to the health crisis. Thus, a more precise inclusion of the initiatives of European cities in general could also make it possible to have a more precise vision of the resilience of cities.

CONCLUSION

This work shows the relevance of the eighth dimension, smart health, in the analysis of smart cities. From a methodological point of view, our work shows how it is possible to enrich the analyses of smart cities with new variables. It is a method of analysis that can be pursued for the living dimension. Indeed, this dimension is constituted of many urban services which would require a more detailed analysis. Finally, this work shows that the smart city model must be questioned from the point of view of resilience to a health crisis. Our results show that it is important to consider the notion of urban health and the axes of the health dimension constitute avenues of reflection for the governance of cities.

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APPENDIX

Table 1. List of variables describing the smart health dimension.

| Variables | Description | Source |
|-----------------------|---|-----------------------|
| health_infrastructure | Number of buildings, shops and offices identified as clinics, healthcare, hospital, laboratories, health centers, hospital, medicine, medical supply center, hearing aid centers and laboratories. | OpenStreetMap* |
| health_speciality | Total number of reports on OpenStreetMap by the tags healthcare specialty avoiding general medicine in the city per inhabitant. | OpenStreetMap* |
| alternative_medicine | Total number of reports on OpenStreetMap by the tags healthcare alternative in the city per inhabitant. | OpenStreetMap* |
| health_proximity | Total number of reports on OpenStreetMap by the tags healthcare specialty of general medicine, doctors, dentists, therapists, healthcare counsel and pharmacy in the city per inhabitant. | OpenStreetMap* |
| health_net_info | Individuals using the internet for seeking health-related information 2019 (% of individuals aged 16 to 74). Health-related information: injury, disease, nutrition, improving health, etc. Within the last three months before the survey. | Eurostat eHealth** |
| health_appointment | Internet use: making an appointment with a practitioner via a website 2018. (% of individuals aged 16 to 74). | Eurostat eHealth** |
| ageing | The number of inhabitants overs 65 years old per NUTS2. | Eurostat Statistics** |
| healthy_life_years | Healthy life years in 2019 by country. | Eurostat Statistics** |
| medical | Total number of reports on OpenStreetMap by the tags health and medical in the city per inhabitant. | OpenStreetMap* |

* Data from OpenStreetMap was extracted on 29 October 2020.

** Data from Eurostat eHealth and Eurostat Statistics was extracted on 25 February 2021.

THE UNEXPECTED CONSEQUENCES OF RECYCLING PROGRAMS: CROSS-CUTTING EDUCATION, RESEARCH AND GOVERNANCE FOR REDUCING PLASTIC WASTE

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ABSTRACT

Plastic waste is a systemic problem impacting everything on the planet. This is acknowledged the world over. The problem won't be solved by better recycling programs alone. Globally less than 10% of plastic produced has been recycled, and production has increased nearly 200-fold since the 1950s. The issue is not so much about improving recycling as it is about reducing the use of virgin plastic.

Little attention has been paid to the continuing rise in new plastic production. Society has grown comfortable with plastic and believes, most often mistakenly, that our waste plastic will be redirected away from landfills and recycled into new products. But plastic bags are not recycled into new plastic bags, plastic bottles don't become new bottles, nor plastic containers new containers. Plastics are recycled into secondary products which at end-of-life are incinerated or shipped overseas to end up as waste.

The very recycling programs intended to deal with the plastic waste problem may in fact be exacerbating it. We discuss whether access to such programs contributes to a sense of ease and acceptance of plastics. We analyse the attitudes and conditions that support the growing problem, and explore cross-cutting solutions including top-down and bottom-up regulatory frameworks and attitude changing initiatives, finding alternative materials, and funding directed research around circularity and effectiveness factors for consumer facing programs.

KEYWORDS

Ecocities; zero-waste; plastics problem; recycling behaviour; environmental values

INTRODUCTION

We all understand that plastics waste is a fundamental problem facing the world today. There is a high level of public and political awareness. In North America we know about the growing problems of the Great Pacific Garbage Patch, marine debris which is actually comprised of the Western Pacific Garbage Patch, located near Japan, a Northern Pacific convergence zone, and the Eastern Pacific Garbage Patch, located between Hawai'i and California. We have participated in, or watched footage of, beach clean-up programs. We have seen the impacts of ocean plastic on sea life, the micro and macro plastic found in stomachs of dead seabirds. Recently we have begun to see plastics enter our own food chain, and to see micro plastics found in our own bodies. We have seen new issues and impacts come to light following China's decision to stop purchasing our plastic waste. It is common knowledge that globally only about nine percent of all plastic ever produced has been recycled, and that single-use product packaging is the main source of waste, accounting for 50% of the total plastic waste.

In spite of this knowledge, if we think about recycling at all, society generally believes, most often mistakenly, that our waste plastic will be diverted from landfills by collection programs, and cleaned, sorted and recycled into new products. In fact, consumers' practical knowledge about recyclability, biodegradability, reusability, and the impact of these on the environment is low [1], [2]. Studies have shown that much of society doesn't rank the environment highly when making decisions about using plastic. The perception may be that plastic is recyclable and so is being recycled, using it is OK and doesn't really harm the environment. Our use of plastic is based on a sense of comfort afforded by recycling programs, and little attention gets paid to the continued staggering rise in new plastic production. The very recycling programs intended to deal with the plastic waste problem may in fact be exacerbating it.

This work follows our earlier investigations into Personal Net Zero [3]. Our earlier work investigated pathways toward zero waste and led us to look more closely at our recycling program, how it operates and how bad outcomes could be turned around. The real issue here is not about improving recycling programs. It is about reducing or eliminating the use of plastic, particularly virgin plastic. Virgin plastic production is increasing. Fossil fuel companies, facing the prospect of growing clean energy technologies like electric vehicles, are pivoting to plastics as way to maintain business as usual. Recycling programs have done little to decrease the impact of plastic waste, and have done nothing to curb production of virgin plastic. This is the framework for this paper.

This paper investigates consumers' attitudes to using plastic given the presence of recycling programs. We discuss whether access to such programs contributes to a sense of ease and acceptance of plastics. We analyse the attitudes and conditions that support the increasing production of plastic, and the potential for alternative materials to be used. We use unstructured interviews with experts and general public, direct observation, and research from secondary sources such as statistical data from government reports and peer reviewed studies.

ANALYSIS

Timeline

Figure 1 shows the global annual plastic production from 1950 to the present. Overlaid on this is a timeline of selected events, actions, and initiatives related to the growing problem of plastic waste.

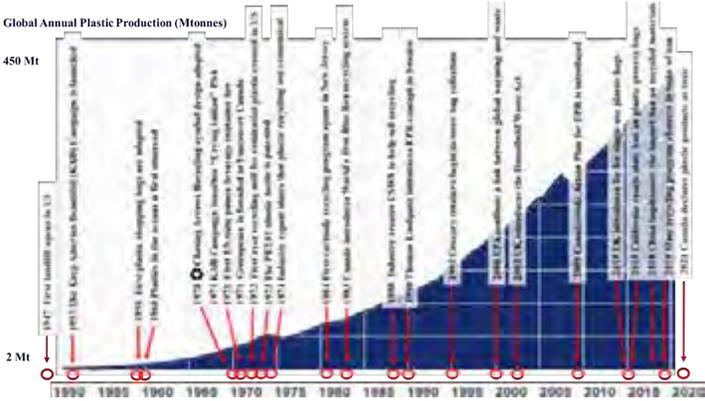


Figure 1: Annual Plastic Production and Recycling Milestones.

Points of particular interest on the timeline include:

- In 1947 the first landfill is opened in the US at Fresh Kills, Staten Island, NY. By 1955 it has become the largest landfill in the world and remains so until it closes in 2001. It is currently undergoing a 30 years reclamation to become Freshkill Park.
- In 1953 *Keep America Beautiful* is launched by a coalition of companies from the packaging, beverage and tobacco industries as an anti-litter campaign.
- In 1959 the first plastic shopping bags are adopted.
- In 1960 the first plastics in the ocean are observed.
- During the 1960s fossil fuel companies aggressively pursue packaging patents.
- In 1970 the now familiar “chasing arrows” recycling symbol is introduced. It is the result of a design competition sponsored by the plastics industry.
- In 1970 the Resource Recovery Act is passed in the US. This is followed by hundreds of attempts to tax or ban plastic packaging; most are blocked by the plastics industry.
- In 1970 the world had its first Earth Day, and the US Environmental Protection Agency (EPA) is created.
- During the 1970s the use of plastic grocery bags becomes widespread.
- In 1971 Keep America Beautiful Campaign’s now famous “Crying Indian” PSA [4] is launched with an anti-litter focus. The advertisement effectively put the onus for responsible disposal of waste items squarely onto consumers, initiating our ongoing tug-of-war with environmental angst.
- Also in 1971 Oregon becomes the first US state to pass a beverage container law, and Greenpeace is founded in Vancouver Canada. Awareness of environmental science begins to spread, landfills are identified as massive space-wasters, the growing waste problem is linked to our consumption behaviours, and environmental legislation including resource recovery and conservation begins to be passed.
- In 1972 the first plastic waste recovery mill is created in Pennsylvania.
- In 1973 the PET plastic bottle is patented.
- In 1974 an internal plastic industry consultant report concludes that it is unlikely plastic recycling will ever be economically viable.
- Prior to 1980 North American plastic waste is considered as trash and is sent to landfills or incinerators.
- In 1981 first curbside collection program is implemented in New Jersey.
- In 1983 Canada introduces the worlds first blue box recycling system.
- In 1988 the US Society of Plastics Industry creates the Council for Solid Waste Solutions to help sell the idea of plastic recycling to the public.
- In 1990 Tomas Lindqvist introduces the concept of extended producer responsibility (EPR).
- In the early 1990’s EPR is implemented as a policy strategy in several European countries.
- In 1992 the number of US curbside recycling programs reach 5400.
- In 1995 major grocery and retailers begin in-store collection of plastic bags.
- In 1995 US curbside recycling programs surpass 10,000.
- In 2000 US EPA confirms the link between global warming and plastic waste.
- In 2003 UK introduces the Household Waste Act.
- By 2006 93% of Canadian households have access to a recycling program.
- In 2009 the Canada-wide Action Plan for EPR is announced.
- In 2015 UK introduces a fee for single use plastic bags, and California enacts a ban on plastic grocery bags.
- In 2018 China implements an import ban on recycled material.
- In 2019, in wake of the China ban, the US experiences mass recycling program closures, recycling reaches a crisis point.
- In 2021 Canada declares all plastic products as potentially toxic, providing a legal basis for banning certain items. The decision that plastics can be considered toxic under Canadian Environmental Protection Act (CEPA) if they harm the environment, biodiversity, or human health, is supported by evidence presented in a 2020 scientific assessment. [5]

From a global total of 2 million tonnes produced in 1950, by 2015 we were producing over 380 million tonnes (resin and fibre) of plastic [6], [7]. Following similar growth trends, production of new plastic by 2021 will be close to 450 Million Tonnes. The point here is that despite the many efforts and the increased public and political awareness, there has been no curtailing of the global production of new plastics.

Why Haven't Recycling Programs Reduced Plastics?

There is a narrative that solutions to the plastics waste problem can be found in recycling. This narrative is actively encouraged by the plastics industry. In response to the Canadian federal government's intention to list plastic as a toxic substance, a spokesperson for the plastics industry stated *we believe that it is not the use of plastics that's the issue it's the end of life management* and further that *problems arise from poorly designed and underfunded waste management systems* [8]. Similarly, in a contest for elementary students, sponsored by an industry lobbying group fighting restriction on plastics, students were asked to design recycling receptacles in a manner that would help promote recycling [9]. It is important to understand that this response is not new. From the advent of recycling programs in the 1970s industry has argued that any problems with plastic waste can be solved by recycling. Recent reporting from National Public Radio (NPR) [10] [11] in the United States indicates that the plastics industry has reportedly spent tens of millions of dollars on long-running public service announcements, promoting recycling and the benefits of plastics. The reporting found that while industry was selling the public on the recycling idea, as early as 1974, plastic industry consultants were privately saying that it is unlikely plastic recycling will ever be economically viable.

A basic expectation of a recycling program is that new plastic items will be made of plastic recycled from old items. The net effect therefore should be that over time the need for new virgin plastic would be reduced. It is clear from Figure 1 that this has not been the case, even with the global development and expansion of recycling programs during the 1990s and 2000s. It is enlightening to try to understand why.

The first consideration is that there is a difference between *recyclable* and what is actually *recycled*. The *chasing arrows* symbol was introduced in 1970, as discussed above. It differentiates between plastic resin types and indicates, in very broad terms, the existence of some form of recycling process. This symbol has become the standard that most consumers use to judge whether a plastic item will be recycled. In actuality, recycling outcomes for each of the resin types, as discussed below, indicates that reliance on this symbol is in most cases misplaced.

Plastics are generally classified into seven types, identifiable by a resin code usually found stamped on the product in the center of the now familiar *chasing arrows* triangle. The triangle and codes are not regulated and are available for anyone to use. Efforts to separate the implied recycling nature of the triangle from the resin codes have been unsuccessful. Table I summarizes the plastic types and codes, some common products for each, an estimate of their recyclability, and what the recyclable plastics are commonly recycled into.

Table I: Plastic Types, Common Uses, Recycling Rates and Common Recycling Outcomes.

| Plastic Type | Typical Products Used For: | Recycling Rate: * | Common Recycled-As Products: |
|-------------------|---|-------------------|--|
| #1 PET (PETE) | Drink bottles, food containers, | 29% | Polyester fibre and fleece garments, pillow stuffing, carpet backing |
| #2 HDPE | Milk or juice jugs, yogurt containers, shampoo bottles, bleach bottles, motor oils | 29% | Pens, plastic lumber, plumbing pipes, blue boxes. |
| #3 PVC | Credit cards, faux leather, vinyl flooring, garden hoses, traffic cones, piping, siding doors | 0% | Generally not recycled. |
| #4 LDPE | Bread bags, sandwich bags, garbage bags, squeeze tubes | 5% | Generally not recycled. If recycled: plastic lumber, benches, compost bins. |
| #5 PP | Syrup and ketchup bottles, hard prescription bottles, deodorant containers, medical equipment, appliance and auto parts, straws, bread bag ties and bottle caps | 1% | Generally not recycled. If recycled: heavy duty items like rakes, cables, ice scrapers, automotive battery cases |
| #6 PS | PS foam: foam cups, takeout food containers, egg cartons, and packing peanuts EPS: building insulation, CD cases and electronics packaging | 1% | Generally not recycled. If EPS is recycled: office accessories, CD cases. |
| #7 Other plastics | multi-resin and mixed plastic items: safety glasses, laptop screens, and shatterproof windows, automotive lights. | <1% | Generally not recycled. If recycled: plastic lumber, picnic tables, engineered fuel |

* Estimated average waste plastic recycled from total collected from [12], and [13].

Resin code 1 (PET or PETE) is considered highly recyclable compared to other types of plastics, and has a recycling rate of between 22 and 30%. It is picked up by most curbside programs and able to withstand the recycling process several times, depending on what it is recycled as. For example as new drink bottles, PET may be able to withstand several rounds of recycling, making it a good candidate for a circular product process. However, when it is spun into polyester fiber, for example for carpets or clothing, and as is often the case, then recycling becomes unrealistic. In spite of its recyclability, roughly 70% of PET plastic bottles are never recycled, and end up in landfills, or our oceans. Some reports [14] claim that of the PET that is collected, only about 10% arrives in good enough condition to be recycled into more water bottles.

Resin code 2 (HDPE) is a hard plastic not as transparent as PET. HDPE is recycled about as often as PET, and is covered by most curbside recycling programs. Its durability makes it easier to withstand the recycling process repeatedly. A European manufacturer of waste and recycling storage systems, reportedly found that HDPE can be recycled 10 times [15]. Studies like this may be conducted under controlled conditions that aren't generally available to current recycling programs. They do, however, demonstrate the potential for improved recycling and circular outcomes for HDPE.

Resin code 3 (PVC) is not recyclable so products made from PVC must be made from raw, virgin material. PVC is more challenging to break down for reprocessing because it is composed of numerous different compounds and can contain toxic additives.

Resin code 4 (LDPE) is soft and flexible and problematic to recycle. Photos of marine life mistaking plastic bags for jelly-fish have made LDPE the poster-child for bad plastic waste management. LDPE items are often not included in curbside collection programs. If LDPE is recycled, it is recycled only once because the quality is so degraded it can only be used for single-use items.

Resin code 5 (PP) is the second most widely produced plastic after PET, but with much poorer recycling outcomes. For example, in the US only about 1% of PP gets recycled

Resin code 6 (PS) is widely considered the least environmentally friendly plastic. PS includes polystyrene foam which generally can't be broken down by standard recycling methods and is too expensive to process. PS also includes EPS (expanded polystyrene) which is the rigid format. EPS is recyclable, but typically only once, and isn't accepted by most curbside programs.

Resin code 7 (Other plastics) is the resin code commonly used for used for miscellaneous plastics like polycarbonate (PC), and polylactide (PLA), a *biodegradable* plastic made from corn starch or sugar cane. Not many curbside services will accept resin code 7 although consumers place items in blue boxes causing sorting and contamination issues. PLA items look nearly identical to PET so the confusion is understandable. Resin code 7 is difficult and expensive to recycle through conventional methods.

From their initiation in the 1970s, recycling programs have grown significantly in scope through the 1990s and 2000s. Even so, it is clear that very little of the plastic that is in use today will have favorable recycling outcomes. Of the 8.3 billion tonnes of plastic produced globally since 1950 only 9% has ever been recycled.

Consider the impact that having recycling programs in place has on consumption behaviour. Having access to recycling programs tends to relieve the inherent guilt of using plastics and provides a basic level of comfort in their use. This is despite the growing awareness of plastic waste as a societal problem. Consumers have a sense that something responsible is being done with the plastic waste that they generate, as long as they sort it out of a waste stream and into a recycling stream. As shown above this is an erroneous belief. The net effect is that the very existence of recycling programs allows more and more new plastics to enter the market.

A final point to consider about recycling relates to how programs have been structured. Recycling has been set up with a business framework where plastic waste is treated as a commodity. The business case for this framework has fundamental problems. The business of dealing with plastics at their end of life is treated as independent from the business of making the plastics initially. The result is that plastic waste handling is reliant on markets that have no connection to the needs for generating new plastics. The markets for recycled plastics struggle to be stable. The effort to resolve this is focused on trying to find recycling processes and markets for what is being collected rather than on finding ways to add circularity to the way plastic products are generated in the first place.

DISCUSSION

We have shown that despite mounting awareness of the problem of plastic waste and growth of and reliance on recycling programs, plastic production continues to grow. Based on our analysis the problems can be characterized by two fundamental issues:

- The fact that most of the plastic that is put into the market is not actually recyclable in a viable sustainable way. Few plastic types have any potential for multiple reuse. Most are either not recyclable or are recycled once and before entering the waste stream.
- Consumer behaviour in the continued use of plastic and reliance on it is based on an erroneous belief in the effectiveness of recycling. This belief allows for the exponential growth in production of new plastics.

These issues suggest the need for a societal response along two avenues. The aim of the first avenue is to affect a wholesale shift in how plastic enters the market, is used, and is then dealt with at the end of its use. This amounts to a paradigm shift away from a linear system for plastics that has waste as the ultimate end point towards a circular process that reuses plastics many times. The aim of the second avenue is to break the comfort level that consumers have in using plastics. What is needed are information initiatives to tie the awareness around the problems to the use patterns. Essentially, this is a targeted public education effort.

The suggested measures presented here are not aimed at expanding or creating a better recycling system. Their ultimate intent is to drastically reduce the amount of virgin plastics that is produced. It should be noted that neither incineration of plastics (which produces GHG at levels equivalent to burning fossil fuels directly) nor the use of bio-plastics (which have their own problematic outcomes) are considered to be sustainable options for reducing plastic waste.

What is meant by *Cross-Cutting Solutions*?

Cross-cutting solutions attack the problem at multiple points simultaneously. In this discussion the cross-cutting nature of the proposed measures include regulatory approaches, consumer facing approaches, suggesting alternatives to particularly problematic outcomes applying directed research. The intent is to solve specific problems by funding the research needed while at the same time attacking the problem through regulation and consumer education. The proposed actions are characterized as direct and specific avoiding the trap of incrementalism which tends to give a false impression of progress in solving the issue while giving space for business-as-usual to operate. Our view is that incremental approaches hide the real issue and delay any meaningful change.

Top-down (government/regulatory focused) Approaches.

With an objective of transforming the current plastics industry from a *plastics* industry into a *recycled-plastics* industry we need to limit the types of plastic we use to those plastics which can be easily and repeatedly recycled. Only those products that can be recycled in a fully circular sense, for example waste products that are processed into new versions of the same products, should be collected and remain in a recycling program. All other types of plastics need to be phased-out and replaced by materials that are sustainable, and fully and repeatedly recyclable.

To achieve this objective, top-down solutions must regulate production and consumption of plastic using enforced bans, implementation of taxes, and mandated recycled content minimums that are high enough that manufacturers can't continue to increase the production of virgin plastics by simply increasing the size of the market. This will need monitoring through a set of meaningful metrics, specific targets, and transparent reporting. And it will require enforcement through fines and similar consequences severe enough to deter target shortfalls.

Regulatory actions could include penalizing use of over-packaging and adhesive labels. They could include mandates to adopt clear and consistent standards for labelling and for data transparency on environmental outcomes. They could include outright bans on plastic products that fail to meet strictly defined recyclability and circular process criteria.

A number of action plans have been initiated in various jurisdictions. Examples are discussed below. Most are voluntary and, while they represent good intentions and could be actionable, without strict accountability they are little more than suggestions and do not represent real solutions. Disruptive as it may be, actions must be made obligatory.

The Australia Packaging Covenant Organisation (APCO) [16] is one example of a co-regulatory product stewardship with targets for increasing the amount of recycled content in plastic packaging, and for eliminating problematic and unnecessary single-use plastics. The Covenant has developed an action plan that identifies problematic and unnecessary plastic items, a timeline for current and planned actions, and future investigations that will be developed over the longer term. The plan also includes a framework for driving a process of elimination, redesign or alternatives replacement that encourages innovation, cross-sector collaboration, and is actionable, specific, and measurable. The plan is voluntary with no real dis-incentives for members who don't meet targets or incentives to exceed them.

The Canadian Plastics Pact (the Pact) [17] has set targets for plastics packaging that are similar to those of APCO. The Pact is working towards defining a list of problematic or unnecessary plastic packaging and measures to eliminate them by 2025. They are supporting efforts towards circularity for 100% of plastic packaging and will require at least 30% recycled content across all plastic packaging also by 2025. These targets are also voluntary with no real dis-incentives for not meeting them, nor incentives for exceeding them.

Greenpeace argues that companies with products containing resin codes 3 through 7 plastics that are labeled as recyclable should be made to remove that language from their packaging. They have further said they will file a Federal Trade Commission mislabeling complaint against those who don't comply [18]. This action could go further still. Instead of simply removing the recyclability language, governments could step in to mandate specific labelling requirements, with monitoring and consequences for non-compliance. For example a requirement to label specified products containing resin codes 3 to 7 as not recyclable, to state the amount of GHGs produced during production, to state both the percentage of recycled content and virgin plastic used in the product, to itemize the additives used and the corresponding health concerns, and to state the specific disposal treatment and the impact of that on the environment and human health, including the GHG and other chemical emissions, and similar impacts.

Bottom-up (individual level) Approaches

Consumer awareness actions can have a direct impact on reducing our comfort levels, and thereby changing our attitudes about use of plastic. It is important to remember that the plastics industry is aware that consumer attitudes have a direct impact on their market, and much of their lobbying is directed towards making consumers comfortable with the use of plastics.

As discussed earlier, the recycling program has provided a strong comfort level and given the perception that outcomes are better than they are. The persistent message to recycle is deeply entrenched and will be difficult to change. Bottom-up solutions are needed that disrupt current perceptions, essentially jar people out of the old recycling mindset and makes it easier for new actions to take hold.

Actions of this type could include using point of consumption product information sheets. For example standard labeling to identify problematic and difficult to recycle plastics, fully transparent communication about the actual consequences of current plastic consumption, regulated point-of-purchase messaging, and education and outreach programs to help the message percolate up and support other society-driven efforts.

Other bottom-up actions could include developing plastic-free aisles in stores and working with suppliers to find ways to minimize plastic use all along the supply chain. For example, one of Canada's larger food retailers [19][20] is a member of the CGF and has set targets including eliminating unnecessary plastic and developing reusable options, and have developed a public facing website for this project. The retailer has a wide breadth of packaging formats across their outlets. This presents a significant challenge, but they are reviewing each type of packaging to improve outcomes. Other retailers, both large and small, could be taking similar actions. Such initiatives are key, showing that it is possible to operate utilizing less plastic, providing space for regulations to act.

Citizen Science activities can engage consumers in developing solutions. We have seen this used in the form of beach clean-ups where citizens participate with researchers to gather data about ocean plastics. The information collected is beneficial to both groups and the open and collaborative process helps to build understanding, knowledge as well as public interest and commitment.

Alternative Materials

Plastic has become ubiquitous in society. It is lightweight, inexpensive, versatile and convenient. If we are to significantly reduce the use of virgin plastics it will be necessary to find ways to make use of alternative materials for many of the most common plastic items in use. Aluminium, glass, and paper all have better outcomes and we consider their increased use as alternatives.

Aluminum is infinitely recyclable and recycled aluminum requires significantly lower energy to produce. For a given ingot, recycled aluminum requires only about 10% of the capital equipment costs compared with those required for the production of primary aluminum. Recycling of aluminum cans saves 95% of the energy required to make the same amount of aluminum from its virgin source, and significantly reduces the GHG emissions from those produced in primary smelting.

Aluminum is versatile and easily formable. Processes already exist to make many aluminum products. Given increased markets for new uses of aluminum other processes would likely be developed. It is the authors' view that aluminum offers the greatest potential to replace plastics over a broad range of products.

Aluminum items would almost certainly be more costly to produce compared to similar plastic items. However, the costs of the resulting plastic waste need to also be considered. Aluminum products would likely have higher value at end of life which would somewhat mitigate increased up-front costs.

The most obvious scenario for aluminum replacement of plastic items is for beverage containers. Aluminum beverage containers are already common up to 500 ml in size. Larger format containers should be entirely feasible.

The use of aluminum is not limited to drink cans. Aluminum tubes are frequently used as packaging from pharmaceutical, cosmetic, and personal care products, to paints, to food items. Aluminum is somewhat heavier than plastic. However aluminum tubes can provide better protection than plastic squeeze tubes due to their heavier gauge material. They also have an aesthetic that many consumers associate with higher brand quality. Aluminum could be considered for replacement of plastic cases for electronics.

Glass may be heavier and more expensive, but like aluminum it is also infinitely recyclable. Recycled glass also has significantly lower energy than virgin glass from new materials. And glass can also be associated with higher-brand quality. Glass containers are also much easier to clean and sterilize than plastic so that the prospect of reuse can be considered.

Paper can be recycled multiple times, and while it does degrade over several cycles, it is still compostable and breaks down relatively quickly once it reaches that end-of-life. Paper is already being used as product packaging. In many cases paper is technically just as viable as plastic for making clamshells for baked goods. Other uses need to be explored for example using pressed paper as a replacement for polystyrene foam trays for selling meat.

Since the pandemic the growing trend of using our own refillable coffee cups, and take-out containers has all but died out. Yet there is little evidence to support this as a necessary change. We also need research to help rebuild consumer confidence in the ability to safely use their own containers for some food and personal hygiene products. For example, semi-permanent, re-usable containers, made from materials other than plastic make more sense as alternatives to single-use plastic. Take-out containers could be replaced with stainless steel tiffins like those used in some parts of Asia and Europe. Making a "new normal" of bring-your-own refillable cup or container could eliminate the need for plastic take-out containers, clamshells and single-use coffee and drink cups, much the same as we see cloth or other reusable bags eliminating plastic shopping bags. Similarly, reusable containers to purchase bulk goods would seem an obvious alternative to single use plastic product packaging.

Funding Directed Research

Directed research provides a bridge between basic and applied research to develop solutions for specific problems. The goal is to focus on finding a solution to small-scope specific problems that will be transferable to other problems. A final solution is achieved through a collaborative, iterative process and is then broadly disseminated. There are several key areas where funding directed research can help towards reducing the growing plastics problem and production of virgin plastics.

Circularity is a fundamental concept that must be adopted if meaningful reductions in plastic production can be achieved. As already shown resin code 1, PET, has potential for being recycled multiple times. A recent study [21] found that PET bottle-to-

bottle recycling is much more feasible than had previously been understood. Some PET bottles containing 50% recycled PET material have been on the market for some time in Europe. Another study [22] reported circular, closed-loop production of PET with 75% recycled content, and some brands even having achieved 100% recycled PET.

Plastic clamshells used to retail many types of fresh foods are also made from PET. However, due to a different forming process as well as certain issues around sorting, clamshells are seldom recycled. Research directed at solving these specific issues could bring PET packaging into a circular process.

Resin code 2, HDPE, because of its durability, has potential for multiple recycling. Typically, HDPE products when recycled are down-cycled, that is made into lower grade products. With some research, circular processes should be achievable. Similarly, research directed at finding ways to recycle plastics made from resin codes 3 to 6, particularly where the problematic issues are related to handling (such as LDPE), has the potential to make big strides in enhancing circularity.

Aluminum, glass, and paper, all have capability for multiple recycling and could replace many problematic plastic products. These may require new forming processes and designs that would benefit from directed research.

Another area for directed research is in identifying the effectiveness of consumer facing programs. We saw earlier that while awareness of the plastics problem is high, consumers' technical knowledge of the issues is low. In spite of being aware of the problem, the perception has been that depositing our recycling in the proper receptacles ensures it will be recycled and generally with a good outcome – namely is recycled back into the same product. We have also seen that labels and messaging for consumer facing material content and recyclability generally lacks transparency, doesn't tell the full story, can be misleading and misrepresent actual outcomes. Messaging and labeling are areas where consumer facing programs are clearly not effective and would benefit from directed research.

Research could be applied to developing new labelling approaches that identify the primary producer of a plastic product so that responsibility for dealing with it at end-of-life is properly assigned. Similarly, new collection processes could be defined that provides consumers easier and more assured disposal options.

These kinds of problems are under-researched, are shared globally, and at scale, the solutions to these problems can become significant contributors to solving the plastics problem.

CONCLUSIONS

We have shown that plastic waste is a systemic problem. That there is a high degree of awareness of the problem. That consumers generally have a low practical knowledge about the recyclability of plastics and the real outcomes of recycling, or about the potential for using alternative materials.

The solution to the problem will not be found by improving recycling programs. The solution to the problem will only be found in reducing and ultimately eliminating plastic use, particularly the use of virgin plastic.

In order to reach this solution requires cross-cutting actions including top-down regulations and bottom-up initiatives, finding and increasing the use of alternative and funding directed research (for example that uses circularity supported by smarter sorting technologies, and identifies effectiveness of consumer facing programs and addresses the transparency, labeling, messaging and literacy issues).

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A LESSON FROM TIDE POOLS: DESIGNING SOCIAL SPACES WITH FLOW

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ABSTRACT

The extraordinary tide pools of the California coastline present a brilliant model for the design of social spaces and a clue to how to tackle one of my country's large-scale social challenges: extreme polarization. In this paper, I posit that polarization is caused by the tendency of people to take on the belief system of those around them, whether a physical or virtual group. Computer simulation reveals that when individual decision-making of this sort accumulates, unmitigated, it leads inevitably to a static end-state in which both sides are locked into their own ideas and opinions. How can we reverse that polarization?

Inspiration comes from the ecosystem of California tide pools, which harbor an incredibly diverse range of sea creatures and serve as a model of mixing, flow, porosity, and change. In tide pools, the regular influx of seawater brings in fresh nutrients and microorganisms and connects discrete pools to create an ever-changing environment. This subtle interplay between consistency and variability (the tide keeps coming in, but each wave brings something different) is crucial to the health of the tide pool ecosystem.

The rigidly uniform social spaces typical of many urban environments and of school campuses, my architectural specialization, contrast with spaces that promote the best qualities of tide pools—mixing, flow, porosity, and change. Unprogrammed “flow” spaces inspired by the ecosystem of tide pools promote the kind of serendipitous individual encounters that can lead to social change, reverse polarization, and revive a more fluid society.

KEYWORDS

Social Spaces; Tide Pools; Ecosystem; Architecture; Flow

A LESSON FROM TIDE POOLS

Having spent most of the past three decades living in the San Francisco Bay Area, I've been blessed with the opportunity to visit the tidepools of Monterey Bay and nearby Asilomar State Beach with my family dozens of times. The Monterey Bay coastline (Fig. 1) has been a spiritual refuge for us, a place where the vastness of the North American continent meets the vastness of the Pacific Ocean, and where, if you head due west, the nearest human beings are 7,000 miles away. The nexus of this encounter between land and sea is a narrow strip of rocky beach no more than a few hundred feet wide, depending on the level of the tide. That such a narrow stretch is home to such a diversity of organisms and ecosystems is a tribute to nature's extraordinary ability to adapt and survive—with crucial lessons for the human beings who until recently had no part in it.

Tide pools occur in the realm between low and high tide, where water washes up and collects in depressions among the rocks. On a furiously windy day, the ocean surges and blasts into the rock formations, sending a powerful spray far up the beach, while in more placid moments, waves trickle into rocky crevices and channels, forming miniature lakes and estuaries. At high tide, these areas are almost completely submerged. As low tide approaches, water drains (and evaporates) from these recesses, and the organisms within them must either survive exposed to sunlight and air or, if they are mobile, relocate further down the beach to submerged areas. The tidepools are thus transitory, while at the same time being a reasonably reliable place to live, since the ocean will predictably flood them approximately twice a day due to the distant pull of the moon and sun.

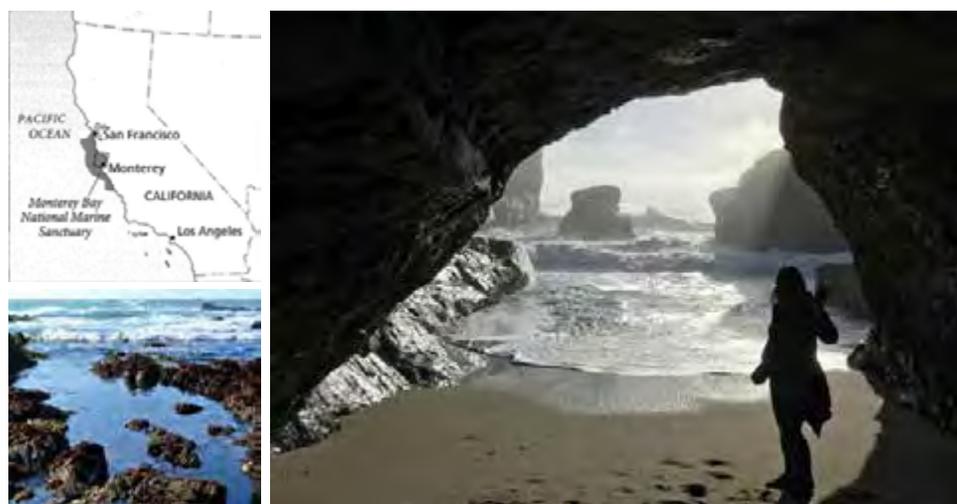


Figure 1. The Pacific Ocean is wild and wonderful. Clockwise from top left: geographic area of the author's research, a rocky cove in the Monterey Bay National Marine Sanctuary, and a view of inflowing tide.

The tide pool's extraordinary range of life (Fig. 2) embraces all shapes and sizes, plants and animals, carnivores and herbivores, species both mobile (clambering hermit crabs, slow-moving sea anemones, drifting seaweed and plankton, coastal birds), and stationary (rooted sea grass, hardy mussels and barnacles that affix themselves to rocks and filter nutrients from passing seawater) [1, 2, 3]. A single pool may contain fish, snails, crabs, spiky sea urchins, soft-bodied nudibranchs, multi-plated chitons, and numerous species of seaweed, sponges, algae, and surf grass. For the human tide pool explorer, a prize find is a brilliant, five-legged orange or pink sea star (commonly and mistakenly called a starfish), submerged and clinging to the edge of a rock or the crevice between two boulders.

The fact that so many different species live side by side does not mean that tide pools are a locus of congeniality. Far from it: everyone's looking out for a good meal. The seemingly placid sea star is a voracious predator that can grasp the tightly closed shell of a mussel, wedge apart the two halves, inject a paralyzing chemical, and then project its stomach inside-out through its own mouth to digest the late bivalve. The tiny owl limpet farms its own algae and bulldozes trespassing consumers by using its shell as a battering ram. The aggregating sea anemone reproduces either sexually (the coming together of female eggs and male sperm) or by cloning itself—pulling itself apart into two halves to become two separate creatures. Two colonies of aggregating sea anemones with genetically different makeups will go to war over territory, declaring a truce by leaving a literal “line in the sand” between them. In a successful ecosystem, not everyone gets along, but there are benefits for all.

Strictly speaking, tidepools are just one part of the larger coastal ecosystem, which ranges from the permanently underwater subtidal zone through low, middle, and high intertidal zones through the splash zone, which lies above high tide but is nonetheless blasted by sprays of water. Beyond the subtidal zone lie deeper zones with other remarkable species. The 10,000-foot deep ocean floor of Monterey Canyon is home to exotic jellies (commonly called jellyfish), cephalopods (like the recently discovered Dumbo octopus), and the elusive giant ocean sunfish. Each of these zones accommodates a subtly different mix of species and is essentially an ecosystem in itself.

Let's examine some diagrams about how tidal flow works (Fig. 3). In this view, looking down, water is shown in blue and rocks in gray. The ocean waves come in from the upper right. Zoom in and you can see some of the creatures shown in the photos. Now watch the flow of water carefully as the tide comes in. At low tide, some sea creatures are left high and dry, exposed to the sun, birds, and land predators. At medium low tide and medium high tide, water flows through cracks and crevices in the rocks and forms larger pools. At high tide, some rocks stick up above the pools that surround them. View the images from right to left and the process reverses. On and on, this cycle repeats, with subtle, ever-changing variations.



Figure 2. The extraordinary variety of sea creatures commonly encountered in Pacific tide pools includes (from left, top to bottom): giant green sea anemones nestled in a narrow pool; orange bat star; striped shore crab; white coralline algae and a (green) Pacific purple sea urchin shell; white gooseneck barnacles, California blue mussels, and slender rockweed algae.

What are the qualities that make the Monterey Bay tidepools a unique, diverse, and sustainable ecosystem? And what lessons can we learn from them? I'm struck by the subtle, loosely-defined boundaries between each tidepool and the rivulets that feed it, the eddies and whorls that spin off of it, the tide pool's changing shape as the water level in it rises and falls, its porous connection to the tidal zones above and below, and the entire coastal environment's combination of constancy and change. Having found their niche in the tidal zone they're most suited to, species can count on the pounding surf to bring in a fresh, ever-changing supply of nutrients. The unique feature of tide pools that allows this ecosystem to thrive can be captured in four related qualities: mixing, flow, porosity, and change—qualities that I will argue are essential to the survival and renewal of a rich and self-sustaining world, whether natural or human-made.

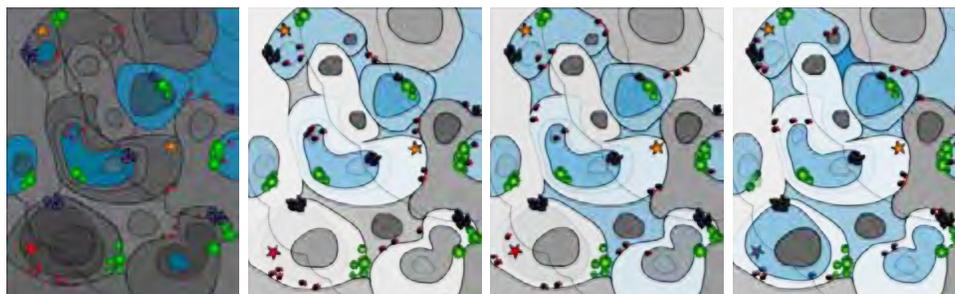


Figure 3. Diagrams depicting tidal flow. Seawater (blue) enters from the top right and fills the cracks and crevices between rocks (gray) on the shoreline. Left to right: low tide, medium low tide, medium high tide, high tide. Zoom in to see sea stars, green anemones, California blue mussels, and hermit crabs.

HOW CAN WE EXPLAIN THE POLARIZATION OF AMERICA?

We live in a time when many communities find themselves divided into opposing camps of people whose seemingly intractable ideologies prevent them from identifying with members of the other camp.

How did that polarization come to be? Can it be reversed? The topic is one of endless debate, with pundits quite rightly adducing theories that draw from politics, economics, sociology, psychology, and the particularly fraught history of my own country. As an architect who has long been inspired by natural phenomena (like tide pools), I came at it from a systems approach. I began with a thought experiment to test whether an initially diverse society can become extremely un-diverse, over time, by the slow and steady accumulation of decisions made by individual citizens.

The experiment starts with an imaginary society of 100 people, randomly distributed in their space (Fig. 4). Close up, they can be seen doing what people do, walking, chatting, reading, talking on a cellphone. They're sometimes social, sometimes not. We now randomly assign each of them either a blue or a red dot. There are 50 of each color, randomly distributed among the dots. We proceed with this hypothesis: people tend to make decisions based on the opinions of the people closest to them, the group with which they most closely identify. Although in the thought experiment we'll be looking at the people (or dots) that are geographically close, and don't move, in real life groups can be quite spread apart. The internet, which once seemed like a democratizing influence, is now overrun by algorithms sending people information that simply reinforces opinions or preferences they already have. Like or don't like? Thumb's up or down? Friend or foe?

To set the thought experiment in motion, we choose 10 of the 100 dots at random. The nine dots closest to each randomly selected dot are identified by the irregularly shaped net around them. I chose the number nine because it's an odd number, so there will always be a majority. It's also the number of justices in the U.S. Supreme Court, a body with enough members to have a variety of opinions without being an unwieldy size.

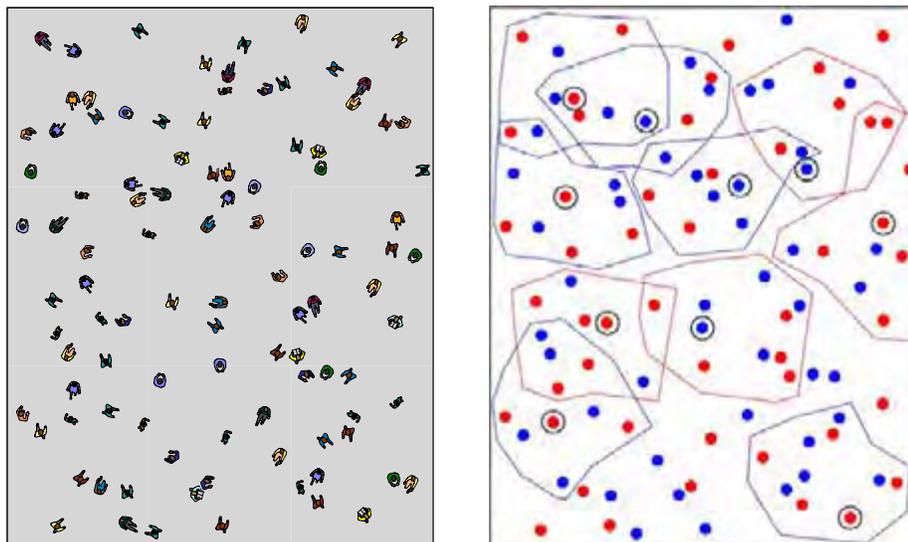


Figure 4. The author's thought experiment. Left: Aerial view of a random collection of 100 people, some of them social, some minding their own business. The experiment arbitrarily assigns half of them a red dot and the other half a blue one, though they are fully mixed. Right: Each individual has been replaced by a dot matching his/her ideological color. 10 dots are randomly selected and shown with black circles. The nine dots closest to each circled dot are captured in a net, whose color reflects the majority color of the nine neighbors. Each selected dot will change color (or not) to match the majority color. The process repeats.

The nets are shown either red or blue to reflect the majority color within them. In keeping with our hypothesis that people take on the opinions of those around them, each selected dot will either stay the same color or change color depending on the majority of dots in its group. When we remove the nets (not shown), six dots will have changed color—four to blue and two to red. Our 100 dots are now slightly less random.

So that's the first step. What happens if we repeat that process, over and over, selecting 10 dots at random, then looping the nine dots closest to them, and allowing the selected dots take on the majority color of their group? When I got this far in my thought experiment, I turned to my son for help producing a computer simulation.

Starting, as before, with 50 dots of each color, randomly arranged (Fig. 5, left), we ran the process ten times (Fig. 5, middle). Look carefully, and you'll see the dots starting to cluster into like-colored groups. After only 20 steps (not shown), the dots had become even more clearly divided, with only a few outliers remaining. By step 30 (Fig. 5, right), the dots had become completely divided. In fact, shortly before step 30, the dots stopped changing color altogether. No matter how many times we repeated the process—we ran hundreds of iterations—not a single dot changed ever again. Each dot is fixed for eternity. Gridlock!

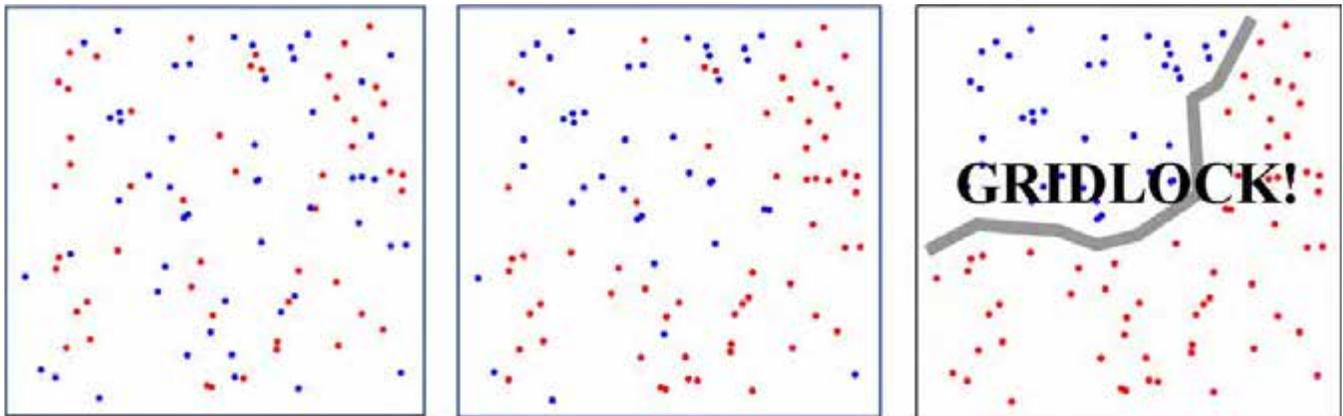


Figure 5. Three stages of the computer model. Left: Step zero, with 50 red and 50 blue dots randomly arranged. Middle: Step 10. Many dots have switched color. Groups have started to emerge. Right: By step 30, two groups are firmly in place, shown separated by a superimposed gray line. They will never change.

We ran many more trials and the same thing happened each time. Each trial led inevitably to gridlock, but perhaps unexpectedly (Fig. 6), even with the same initial condition, the final configuration was different each time.

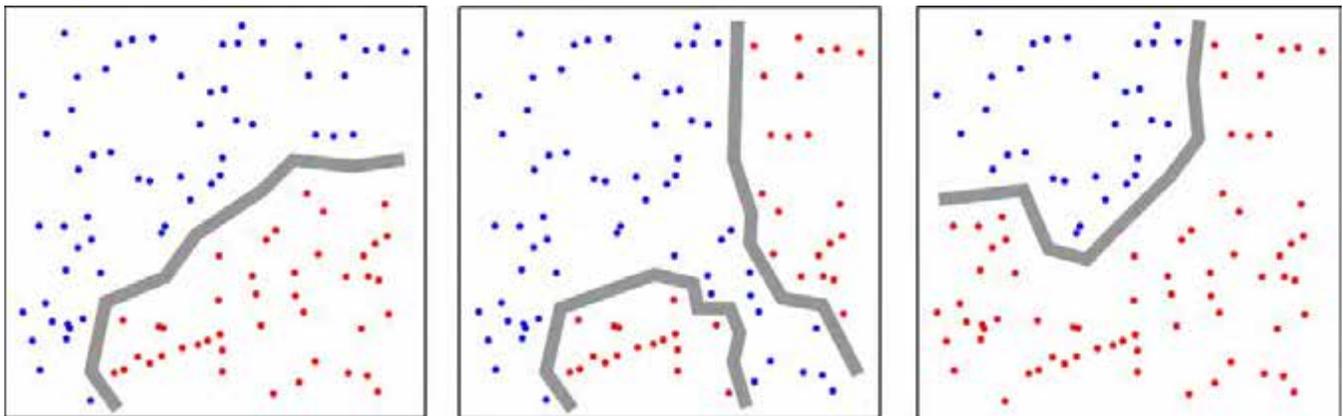


Figure 6. Three end results from another trial. Beginning with the same initial condition and different random selections of 10 dots, each of the three ended with a different final state—but, inevitably, gridlock.

It turns out that ours was not the first simulation to reach this conclusion. A half-century ago, the Nobel Prize-winning economist Thomas Schelling published a strikingly similar study [4] (selected diagrams shown in Fig. 7) to explain how racial groups become segregated (instead of a computer, Schelling used dice). Interestingly, Schelling came from Oakland, California, where I live, a city that has long had a complex mix of ethnicities.

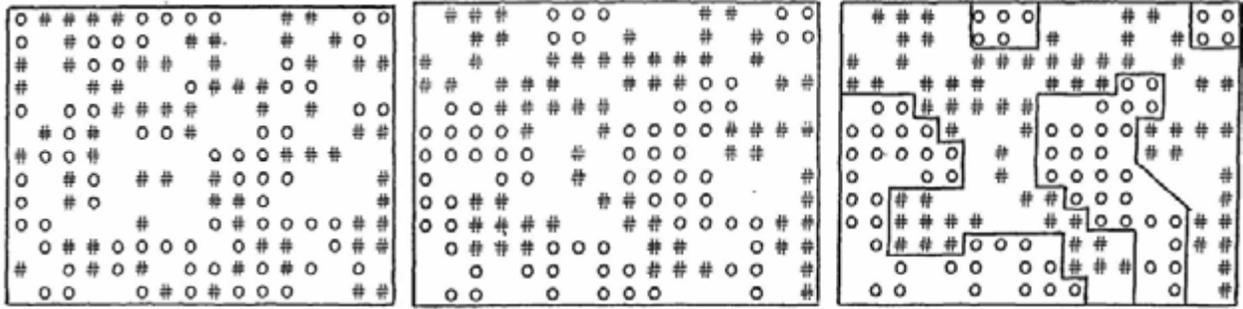


Figure 7. Economist Thomas Schelling's "Dynamic Models of Segregation" study of how racial groupings evolve has much in common with the author's analysis. Left to right: random, clusters, clusters delineated.

Our computer model had successfully shown, based on an initial assumption of how people make decisions, that a society that starts out diverse can become, over time, extremely un-diverse and polarized. Our next step was to increase the society size from 100 individuals to 1,000 to see what difference that would make.

We started with 1,000 dots, 500 of each color, randomly arranged, and ran the program through hundreds of steps. With ten times as many dots, it took considerably longer to reach gridlock, but the result was the same. Fig. 8, left, shows the final step, unchanging and gridlocked, but with more complex clustering than in the configurations of 100 dots. This higher-order clustering bears an uncanny similarity to the superclustering of galaxies in space (Fig. 9, middle), in which clusters of galaxies, held together by gravitational attraction, form superclusters that are themselves held together by gravitational attraction. Whether this resemblance is merely superficial or evidence of a more profound, systemwide connection remains to be seen. (We might need to generalize our model to include effects not just between adjacent individuals [dots] but between adjacent communities [clusters of dots].) Ideological clustering at a larger scale than in our collection of 1,000 dots is quite evident in a graphic statistical analysis produced by The New York Times [5] (Fig. 8, right) that looked at segregation by political party in dozens of metropolitan areas. In this representative image, the higher-order clustering recalls both Schelling's results and ours.



Figure 8. Higher-order clustering. Left to right: Gridlocked condition in computer model of a 1,000-dot society, representation of galaxies in space, and political affiliations in a human population, the city of Houston, Texas.

HOW DO WE REVERSE THE POLARIZATION OF AMERICA?

Now that we had uncovered a possible mechanism for how societies become polarized, our next (and crucial) question was whether, using that model, we could reverse polarization. Having been inspired in this pursuit by the extraordinary ecosystem of tide pools, I turned to it for solutions. So my son and I took our gridlocked ecosystem of 1,000 dots and sought to unwind it using the key features of tide pools: mixing, flow, porosity, and change.

To capture the impact of tidal flow, which stirs up the local environment and brings in fresh micro-organisms and nutrients, we thought of a process that would do the equivalent for human society, bringing in fresh ideas and other changes to the local environment. Our idea was not to change the way people think—we assumed that human nature will still lead people to take on the ideas of the group around them—but to introduce periodic, system-wide change just strong enough to disrupt that one-way process. Before every nine steps of the decision-making process that previously led to gridlock, we introduced a computer-generated “tidal wash” by which 5% of the dots would automatically change color. This seemed like a fairly small intervention, but we hoped that after many iterations, it might produce a significant result.

We started where we had left off, at gridlock, which we now labeled step zero (Fig. 8, left). In step 1, we introduced the first tidal wash. The next nine steps consisted of the same decision-making method as before, followed by another tidal wash at step 10. The result after step 10 (Fig. 9, left) reveals only a slight difference from step zero, barely noticeable. By step 20 (not shown), the third tidal wash, the defined groups had begun to break up a bit. We studied the results after steps 50, 100, 500, and 1,000 and were pleased to see that the regular application of tidal washes was making a slow but cumulative difference.

After thousands of cycles, a recognizable pattern emerged: configurations of dots nowhere near random, and not quite orderly, but instead characterized by ever-changing clusters. Though several hundred dots had not changed color at all, hundreds of them had, perhaps many times over (we would have had to check each iteration to follow the life history of each dot). The pattern was not static; gridlock was nowhere in sight. The result is perhaps best captured in an enlargement of a portion of our final step, number 3,690¹ (Fig. 9, right), which shows all 3,690 steps superimposed. Dots that are pure red or blue haven’t changed, but dots that are purple have changed at least once and perhaps many times. Tidal flow has significantly impacted this ecosystem.

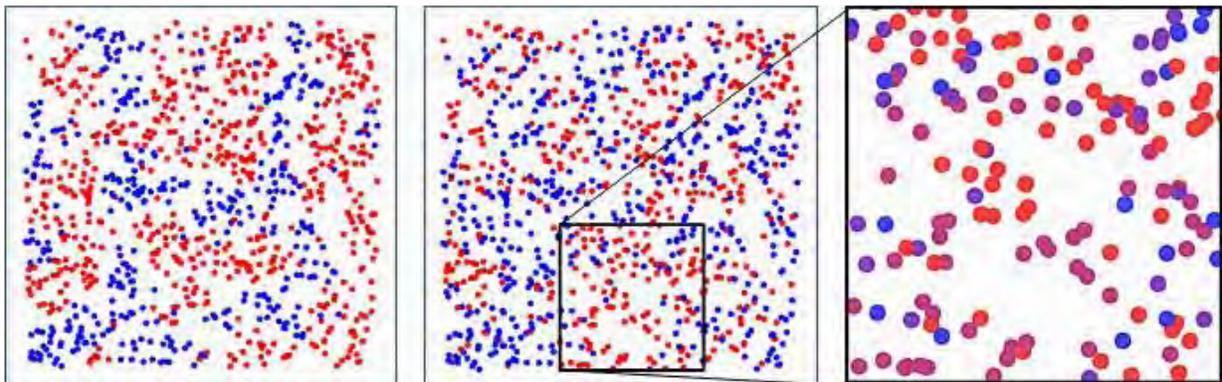


Figure 9. Using tidal wash to depolarize a gridlocked society of 1,000 dots (for step zero, see left-hand image of Fig. 8). Left: Step 10, after the second tidal wash. Close inspection reveals that several dots have changed from their initial state. Middle: Step 3,690. After hundreds of tidal washes, many of the superclusters have broken down, but groupings remain. Right: When all 3,690 steps are superimposed, as shown in this enlargement, red and blue dots are ones that have stayed the same throughout, while purple dots have changed color, possibly many times.

A sequence of graphs quantifying the system’s “tendency to cluster” (Fig. 10) clarifies how the process leads to a kind of dynamic equilibrium. (In a given step, we select ten people at random who consider switching color. The tendency to cluster is the fraction of people that *would* change if they were the ones selected.) At step zero, the system has a tendency to cluster value of 1.000 (gridlocked). The tidal flow introduced in step 1, and every tenth step thereafter, is the steep line angling downward showing a move toward randomness. Over the next nine steps, the system climbs slowly back toward gridlock, but doesn’t get much higher. By around step 100, the cumulative curve starts to flatten—meaning that succeeding tidal washes have less impact, in part because the system is now farther from gridlock—and by step 500, the curve shows clear signs of leveling off. By step 3,690, the graph strongly suggests that the system will continue to oscillate somewhere between gridlock and randomness, with a tendency to cluster value somewhere between 0.70 and 0.75.

If the parameters were to change—by tidal washing every 20th step, for instance, or by changing the color of only 2% of the dots each wash—the result could well be quite different. As we know from scientists’ study of natural ecosystems, even a small change in one parameter—like an increase in temperature due to climate change—can have a drastic impact on the stability of the entire system. In the Monterey Bay, scientists have learned that a reduction in the population of sea stars caused by ocean warming has led to an overabundance of sea urchins (a favorite food of sea stars) and a precipitous drop in the biomass of kelp forests (a favorite food of sea urchins). The loss of habitat created by the reduction in kelp forests now threatens the many

dozens of fish, crustacean, sea mammals and other species that harbor within them. In an effort to return the ecosystem to its former balance, environmentalists in Monterey Bay are working to promote the population of sea otters (once hunted almost to extinction) who, it turns out, feed voraciously on sea urchins. Since kelp forests sequester up to 20 times more carbon per acre than land forests [6], their survival is intimately tied to our own.

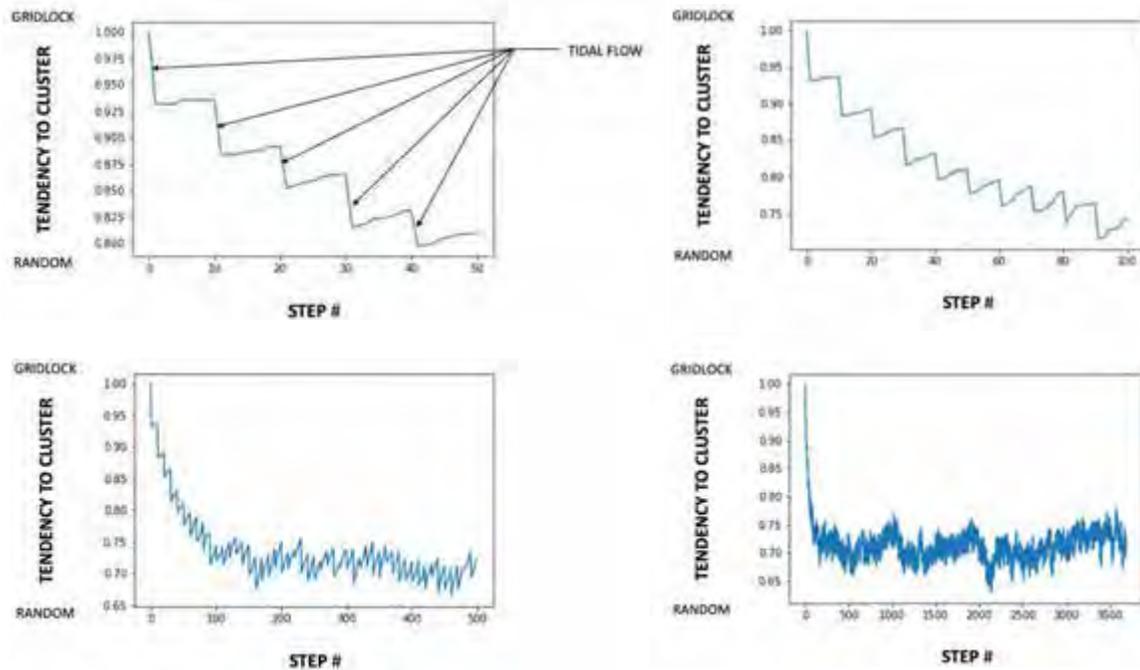


Figure 10. Graphs showing how the tendency to cluster evolves as a result of tidal flow. Left to right and top to bottom: steps 50, 100, 500, and 3,690. The system gradually reaches an ever-changing equilibrium poised between gridlock and randomness.

So what have we learned about reversing polarization? Tidal flow—the ongoing introduction of ocean nutrients, new ideas, or other forms of systemwide variation—brings mixing, flow, porosity and, importantly, change. Instead of marching inexorably towards stasis (and crisis), groups in this more fluid society continuously change over time as members shift from one group to another. The resulting society survives and thrives.

HOW DO WE DESIGN SOCIAL SPACES WITH FLOW?

Finally, we come to the question of what it means to promote tidal flow in human society. Our organizational model suggests that just as it takes the slow accumulation of individual decisions for a diverse society to evolve into one that is decidedly un-diverse, it will likewise take hundreds and thousands of small interactions, over time, to shift society back toward diversity. Even if we do it right, it may take many years. Because I’m an architect who designs schools, a university instructor, and a parent, I have faith that promoting open-minded thinking among young people is key to changing the system. There’s much in America’s educational system that is beyond the purview of architects, but I am qualified to weigh in on the physical school environment. How students interact in their physical space is essential to either fostering or thwarting human development and healthy relationships.

The spaces we humans make for ourselves can be rigid and defined: rectangular rooms with doors leading to rectangular corridors leading to other rectangular rooms with doors. Or, they can be the opposite: loose and irregular, interior leading to exterior, flowing into other irregular spaces with nooks and crannies, whorls and eddies, of their own. Alas, most public schools are more like the former—collections of self-contained spaces that restrict movement and choke off informal communication. Public school campuses (Fig. 11) are traditionally determined by programmatic needs and body counts: the classroom where an average of 32.4 students sit in straight rows, consuming information imparted by the instructor; the linear hallway flanked by metal lockers, a presumably efficient transportation corridor from classroom to classroom; the dining hall, for the provision of food; the multipurpose space with rows of chairs and pull-out tables, for assemblies, indoor sports, and after-school activities; and the play courts and fields, wide open expanses of asphalt, dirt, and (sometimes) grass.

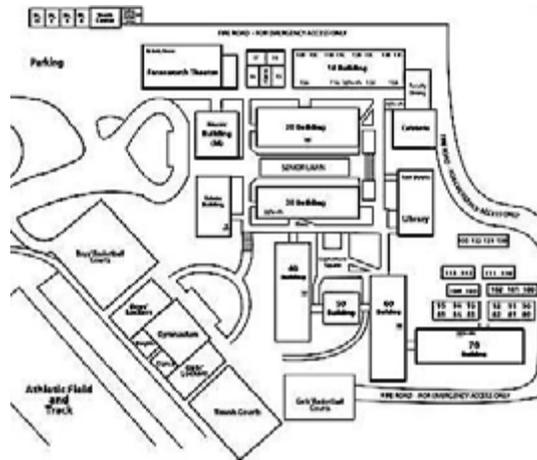


Figure 11. Site plan of Skyline High School in Oakland, from the school website.
The tight, uniform spaces between buildings do not foster unprogrammed, informal gatherings.

But what if we reconsider spaces in schools not in terms of their programmatic content but in a different way, as portions of an ecosystem where virtue is made of mixing, flow, porosity, and change? What if the overlap of human spaces were to function much as mixing zones do in the coastal ecosystem, providing opportunities for informal coming and going, serendipitous encounters, the untrammelled exchange of information, emotions, and ideas? Here are some scenarios that can only take place in such a fluid ecosystem:

- Some elementary students are eating lunch at a picnic table adjacent to the playground. A boy who is not part of that group wants to situate himself so he can overhear the conversation and be seen—just in case the group wants him to join. Because the playground has been designed as a collection of loose, intersecting social spaces, he’s able to perch himself on a nearby seat wall. The group starts talking about a topic he knows something about—the latest superhero movie—and he seizes the opportunity to chime in. When they respond favorably, he summons the courage to join them.
- A middle school has been designed with classroom spaces arranged in a loose “pod” with easily-accessible, irregularly-shaped breakout areas. The teacher sees that a couple of students are having trouble with the material. Knowing that another student has mastered this topic and has shown a predilection for mentoring others, she announces that the class will briefly break into study groups and encourages those three students to gather in one of the breakout areas. The informal arrangement of the classroom spaces allows for the easy dispersal of the students for a short period of time—still all within the teacher’s sight—and then their return, just as easily, to the original teaching space.
- A group of high school students is sitting on a set of broad steps. The steps are part of a circulation path, but just enough out of the way that you can settle there without obstructing traffic. They spot another student walking by and ask her to join the conversation. There’s only five minutes until class time, but it’s just long enough for this crucial exchange.
- At a community college potluck gathering on a warm fall day, the retractable doors of the dining hall are opened up to allow students the choice of sitting either inside or out. The adjacent exterior patio has been designed with a stepped embankment allowing informal seating, perfect for the kind of quick conversations the students carry on before returning to the dining hall for more food and then moving on to join a different group. During one of these conversations, two students discover a shared passion for a favorite science fiction author. What begins as a casual chat ends up leading to a stimulating and profound discussion of what the future holds for humankind.
- A school has been designed with a controlled exterior entry passage to ensure “eyes-on” by the administrative staff in the reception area. However, the passage is more than a tunnel with metal gates. It has a bench on either side, recessed display areas showing student artwork and posters for activities, the return slot for library books, and even a protected monitor showing highlights of the recent school dance competition. Parents dropping off their kids linger and talk about the latest challenges due to the Covid-19 pandemic. There is an unexpected exchange between two parents of differing ethnicities about the current political situation, and each comes away pondering a comment by the other he had not previously contemplated.

Social mixing zones create opportunities for the imparting of new thoughts from one individual to another, one small group to another. And that, in turn, facilitates the flow of information, a situation much less likely to occur in a restrictive physical environment—the box-shaped room, the rectangular corridor, the closed door. At its best, the give-and-take of those encounters is just what turns

questioning adolescents into mature and thoughtful citizens. Are the ideas exchanged in these encounters likely to dislodge America’s political impasse? Not in a day, not in a week, not even in a year. But over time, they add up. It may be idealistic to think that promoting mixing, flow, porosity, and change in the design of schools will promote depolarization, but why not start here?



Figure 12. The author’s design of the entry building to a school campus. Perspective views of the building’s front (left) and rear (right) reveal numerous opportunities for social mixing.

What does a collection of fluid social spaces look like? Let’s study one example, a design I did of the entry building (Fig. 12) to a middle school campus in California’s Bay Area. The building contains administrative offices and student services (counselors, psychologists, speech therapists, etc.) on the lower floor and the student library on the upper floor. The covered passageway at center is the gateway to the campus. The irregular shape of the building, its openness to the exterior along two axes, and the deliberate placement of social mixing zones within the building and around its perimeter (Fig. 13) all create opportunities for informal gatherings and serendipitous encounters.

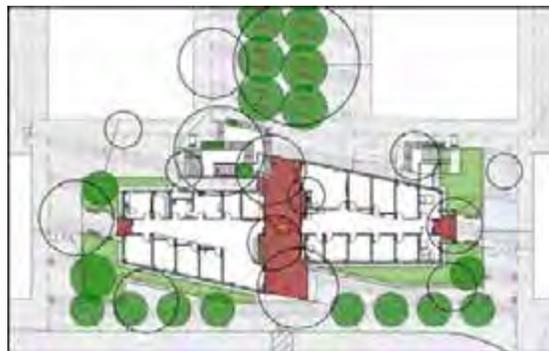


Figure 13. Site plan, with the building’s front at the bottom and the main campus beyond the drawing at the top. Circled areas show social spaces designed for unprogrammed encounters.

Close-ups of three of the social spaces show the variety of encounters that can happen there. At the entry to the building (Fig. 14, left), students run into each other at the start of the school day and can linger with friends on a landscaped seat wall. The covered passageway (Fig. 14, middle) is likewise a place for students, teachers, or parents to pause and chat, read announcements on a video monitor, view student art projects in a display case, and drop off a library book. The library stair (Fig. 14, right) deliberately projects into the central axis to prompt serendipitous encounters. The stepped seating is a central location where one can read a book (or pretend to) while secretly surveying the social scene.



Figure 14. Enlargements of three of the intentionally-designed yet informal gathering spaces along the central passageway.

When places to hang out are on the path to getting where you need to go, you run into people you know and people you don't. Trees, planters, benches, doorways, overhangs, nooks, crannies, whorls, and eddies are all discrete places with individual character. Their interconnectedness provides opportunities for mixing and flow. With its profusion of unprogrammed and in-between spaces, the campus is a diverse and lively ecosystem that promotes mixing, flow, porosity, and change, much like. . .

The tide pools that inspired it.



Figure 15. Ecosystem of social spaces inspired by tide pools. Can it revive a more fluid society?

ACKNOWLEDGMENTS

The author extends his appreciation to his son, Gabriel Perko-Engel, for computer modeling and insightful comments, and to his entire family for lively discussions of the contents of this paper. Additional thanks to the economist Margaret Meyer for helpful criticism and for passing along the work of Thomas Schelling. The image of clusters of galaxies is by Mikkel Juul Jensen, courtesy of Science Photo Library. Thanks to Quattrocchi Kwok Architects and Gates + Associates for permission to use my architectural design shown in this article.

NOTES

1. The computer fell asleep after step 3,690. By then, my son was immersed in final exams; we had run out of time.

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NEIGHBOURHOOD LIFE CYCLE ASSESSMENTS' SENSITIVITY TO MODELLING APPROACH

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ABSTRACT

Life Cycle Assessment (LCA) is a data-intensive approach that has proved its value in environmental evaluation by providing decision-makers with high-quality, multicriterial comprehensive results. For its data intensity, LCA's application at the urban scale is additionally challenged by the scale's intricacies, which significantly amplify the amount of data required. For a complexity compromise, data collection can be reduced to a manageable amount by subdividing the studied area into smaller urban cells such as neighbourhoods, by grouping urban layers into a limited set of aggregates with similar characteristics, and by defining archetypes to represent each group. This paper compares different data modelling strategies bearing different data collection needs to generate neighbourhood LCA input. Data was modelled using: five different aggregation scenarios for building stock, operational energy, operational water and mobility; three different aggregation scenarios for urban infrastructure; and two food consumption scenarios. These were then combined into five final representative scenarios and five neighbourhood LCAs were performed. Subsequently, a scenario uncertainty analysis and a global sensitivity analysis were carried out. K-medoids clustering, ArcGIS, SimaPro v.9 and @Risk supported the assessments. Findings showed that building stock, operational energy and operational mobility are the three most contributing urban layers and by considering them plus any other, results represent more than 80% of neighbourhood impacts. Envelope exclusive scenarios should be pursued only when contemplating an average impact apart for building services. And scenario uncertainty analysis and global sensitivity analysis seem to suffice for the scale as they show where practitioners should return and refine data collection.

KEYWORDS

Sustainable urban development; Life cycle assessment; Neighbourhood scale; Data modelling;
Scenario uncertainty analysis; Global Sensitivity Analysis.

INTRODUCTION

Over 55% of the world's population already live in urbanized areas and, by 2050, urbanization is expected to be somewhere between 65% (in less developed areas of the world) and 86% [1]. That means that our cities – that today only occupy 2% of the global surface but already have a critical impact on the environment – will grow significantly to accommodate the incoming population. Social and economic development can only be achieved if natural resources are sustainably managed within the planet's capacity [3], but producing and operating the built environment responds for substantial impacts, like 36% of global final energy use and 39% of energy-related CO₂ emissions [2]. Given these impressive figures, such impacts should be consistently assessed to detect hotspots and develop strategies to support decision-making towards sustainable development goals.

To that end, Life Cycle Assessment (LCA) has proved its value in environmental evaluation by providing decision-makers with high-quality, multicriterial comprehensive results [4]. LCA is a data-intensive approach though [5], and its application to urban assessments is additionally challenged by intricacies of the urban scale, which further amplify the amount of data required. Thus, when pursuing reliable results, it is important to find a balance between required and feasible information collection, and determine the best way to handle data quality and uncertainty [6]. For a complexity compromise, data collection can be reduced to a manageable amount by subdividing the studied area into smaller urban cells such as neighbourhoods [7]–[9], by grouping urban layers into a limited set of aggregates with similar characteristics, and by defining archetypes to represent each group [10]. Subsequently, results can be up- or down-scaled, as needed.

This study explores how data collection and modelling methods influence the data requirement-modelling quality balance in neighbourhood LCAs, as part of a three-phased research project aimed at developing a methodological framework for performing LCA at the neighbourhood scale (**Figure 1**). Five top-down and bottom-up data modelling strategies – Bottom-up (BU), Mid-up (MU), Mid-mid (MM), Mid-Down (MD) and Top-Down (TD) – are compared to strategically improve modelling while balancing data collection needs of neighbourhood LCA.



Figure 1 – Research project phases and urban layers considered

METHOD

The method comprised four main steps. First, we established the main methodological choices for all LCAs to avoid bias. Second, life cycle inventories (LCIs) were developed considering twelve urban layers and following different TD and BU data modelling strategies distributed into five main scenarios (BU, MU, MM, MD and TD). Third, five LCAs were carried out, observing identical steps and main methodological choices. And finally, results of all approaches were compared and analysed.

Methodological choices

- *Case Study Reference Neighbourhood* – The University of Campinas’ Campus, located in Brazil and comprising of 601,012 m² of total built area distributed in several different land uses [11].
- *LCA Stages* – Raw material extraction, transport to manufacturing site and manufacturing of the product itself in the product stage (Modules A1-A3); transport of the product to the construction site and installation activities in the construction process (Modules A4-A5); mobility maintenance, replacement, operational energy, operational water, operational mobility and food consumption in the use stage (Modules B2, B4, B6, B7, B8 and B9); and deconstruction, transport to waste/recycling processing sites, waste processing and disposal in the end of life stage (Modules C1-C4) [12];
- *Urban Layers* – We considered eleven urban layers typically comprehended in urban development projects (building stock, green areas, energy network, mobility network, water supply network, rainwater network, sewerage system, building stock operational energy, public sector operational energy, operational mobility and operational water) and a complementary layer frequently found in urban metabolism studies (food consumption) (**Figure 1**);
- *Reference Year* – 2019;
- *Reference Study Period* – 50 years, as it corresponds to the average reference study period commonly considered in building LCAs [13] and the minimum reinforced concrete structure building performance [14], [15].
- *Functional units* – Several functional were used units to enhance comparability (m² of built stock GFA; m² of total built area – including building stock and urban infrastructure; per capita; and km² of neighbourhood land);
- *A1-A3 Modelling* – The background system was composed by coefficient values estimated using Ecoinvent 3.4, 3.5 and 3.6 as background data source; Cumulative Energy Demand (CED) v1.11 and CML-IA baseline v3.05 impact assessment methods; and its adaptation to the Brazilian energy matrix using SimaPro 9. In the absence of background data, three environmental product declarations were used (for vinyl tile, asphalt mixture and stainless steel).
- *A4-A5 Modelling* – We considered the typical freight transportation and fuel found in Brazil (road truck and diesel) and quantified their upstream impact using the Ecoinvent database adapted to the Brazilian energy matrix. Distances between the construction site and the nearest materials’ manufacturers were estimated by Google maps. The energy consumed during the construction installations process was estimated based on literature [16] and the quantities of construction material losses were estimated based on the National Budgets Price Composition Table (TCPO).
- *B2 and B4 Modelling* – To estimate vehicle maintenance (B2) we used existing datasets; and to estimate the replacement of construction materials (B4), each construction process’ service life was established using the Brazilian building performance standard [14].
- *C1-C4 Modelling* – The waste and recyclability shares of all replacement and EOL mass were extracted from the Sectorial Survey of the Brazilian Association for the Recycling of Construction Waste and Demolition [17].
- *LCIA Modelling* – The impact assessment methods used were Cumulative Energy Demand (CED) and CML 2001 baseline. Thirteen impact categories were considered: Non-Renewable Primary Energy [PE_{nr}]; Renewable Primary Energy [PE_r]; Abiotic Depletion [ADP]; Abiotic Depletion (Fossil Fuels) [ADPF]; Global Warming Potential [GWP]; Ozone Layer Depletion [ODP]; Human Toxicity [H_{tox}]; Freshwater Aquatic Ecotoxicity [FWA_{tox}]; Marine Aquatic Ecotoxicity [MA_{tox}]; Terrestrial Ecotoxicity [T_{tox}]; Photochemical Oxidation [PO]; Acidification Potential [AP]; Eutrophication Potential [EP].
- *Uncertainty Analysis* – Was composed by Uncertainty Characterization (in which we delineated the multi-scenario at hand and chose the best probabilistic distribution for each type of data); Uncertainty Propagation (using Monte Carlo sampling stochastic modelling); And Global Sensitivity Analysis (correlation analysis). The software @Risk supported the assessment.

Life cycle inventories

Table 1 summarizes the main methodological choices and aggregation scenarios for all LCAs. The foreground systems of the LCIs were composed by data collected and modelled using:

- Five aggregation scenarios for the neighbourhood building stock modelling (BUbs, MUbs, MMbs, MDbs and TDbs);
- Three aggregation scenarios for the neighbourhood urban infrastructure modelling (BU_{urb}, MM_{urb} and TD_{urb});
- Five scenarios for operational energy, water and mobility – based on local, municipal, state, regional and national data;
- And two food consumption scenarios – based on local and national data.

In the BUbs building stock modelling scenario, neighbourhood buildings were modelled using nine archetypes derived from cluster sampling [10]. The mass balance of construction materials was calculated using the complete bill of materials of each archetype (including infrastructure, superstructure, external enclosure, internal partitions, finishing, roofing, doors and windows and building services) and the total amount was then extrapolated to each cluster representative area. Lastly, a final bill of materials contemplating all Campus' buildings was created.

For the MUbs scenario, the building stock was also modelled using the nine 'local archetypes' derived from clustering sampling [10], however, the mass balance of construction materials was calculated considering only the envelope of each Archetype (which including superstructure, external enclosure, roofing, doors and windows) and the total amount was then extrapolated to each cluster representative area. The intention behind this scenario was to explore if using only the buildings' envelopes would suffice for the building stock modelling and thus shorten data collection process.

The MMbs building stock scenario followed the same principles of the MUbs, except for the fact that – instead of nine representative buildings – it was modelled based in only one archetype, the most common type of building in the campus, derived from a visual analysis of the neighbourhood. This scenario aimed at representing time/resource-sensitive situations in which developing a clustering procedure would not be a feasible option and understand the consequences of this circumstances.

In the MDbs scenario, the building stock of the neighbourhood was modelled using an educational building benchmark representing a 'national archetype' (a reference school from the National Education Development Fund). The complete bill of materials of the reference building (including infrastructure, superstructure, external enclosure, internal partitions, finishing, roofing, doors and windows, installations and building services) was extrapolated the entire neighbourhood area.

Finally, for the TDbs scenario, the building stock was modelled using the basic batch of material inputs per 1 m² of GFA of construction established by the Brazilian 'Construction cost assessment for real estate development' standard [18]. The bill of materials was calculated by extrapolating these material masses to the entire building stock area of the neighbourhood.

Table 1 – Summary of main methodological choices of all neighbourhood LCAs

| Goal | Comparison of five neighbourhood LCAs using different modelling approaches ranging from Bottom-up to Top-down | | | | |
|---------------------------|--|------------|---------------|---------------|---------------|
| Scope | Cradle to grave (A1-A5; B2; B4; B6; B7; B8; B9; C1-C4) | | | | |
| Reference year | 2019 | | | | |
| Reference study period | 50 years | | | | |
| Building Performance | ABNT NBR 15575 | | | | |
| Functional units | m ² of building stock built area; m ² of total built area (Bs + Urb); per Capita; km ² of neighbourhood | | | | |
| System limitations | Removal of B1, B3 and B5 stages; B2 was considered only for mobility; EEG adaptations; Use of three EPDs | | | | |
| LCI (Foreground system) | BU | MU | MM | MD | TD |
| Building stock | BUbs | MUbs | MMbs | MDbs | TDbs |
| Urban infrastructure | BUurb | MMurb | MMurb | MMurb | TDurb |
| Operational energy | Local data | City data | State data | Regional Data | National data |
| Operational water | Local data | City data | State data | Regional Data | National data |
| Operational mobility | Local data | City data | State data | Regional Data | National data |
| Food consumption | Local data | Local data | National data | National data | National data |
| LCI (Background system) | Ecoinvent 3.4, 3.5 and 3.6; EPD | | | | |
| Impact assessment methods | Cumulative Energy Demand (CED) v1.11 and CML-IA baseline v3.05 | | | | |
| Impact categories | PEnr; Per; ADP; ADPF; GWP100a; ODP; Htox; FWAtox; Matox; Ttox; PO; AP; EP | | | | |
| Uncertainty Analysis | Scenario uncertainty analysis & Global sensitivity analysis using @Risk | | | | |

Urban infrastructure was modelled as a combination of six urban layers – green areas, energy network, mobility network, water supply network, rainwater network and sewerage system. For the BUrb scenario modelling, we used the best data available at UNICAMP to date, that is, the university’s geographic information system (GIS), which is organized and maintained by the Executive Board of Integrated Planning (DEPI). However, that database is still under construction and is composed by data collected from different sources and periods of time, with different data quality levels. The data acquired referred to natural environment; building stock; streets; sidewalks; parking lots; public areas; physical barriers; lighting poles; energy network; communication network; water supply network and reservoirs; fire hydrant; urban drainage system; manhole; and sewer system. Only a fraction of these objects already had materials attributed to them, so these were collected through site visits and visual image analyses using Google Earth. Minor elements (such as gutter and curbs) estimates used average values per street length unit.

For the MMurb scenario, several steps were taken to model the urban data. First, we characterized the mobility network by measuring the area of all roads, sidewalks, central flowerbeds and parking lots on campus and qualifying its construction materials using image analysis tool (Google Earth). Second, the underground infrastructure estimates were based on local construction practice and expert judgment. For the water supply network modelling, we considered a mesh supply network with piping along each sidewalk and a valve drawer every 3km of pipeline; we used image analysis to estimate the water reservoirs dimensions; and considered two external fire hydrants per building. For the rainwater infrastructure, we considered a gutter line on either side of the street; two drainage sinks every 60m of street; a manhole for each 2 drainage sinks; a main gallery with an average of 60 centimetres diameter concrete pipeline; and 40 centimetres diameter secondary ducts to connect the drainage sinks to the manholes. For the sewerage system, we considered a supply network with piping along one of the sidewalks of the road and a valve drawer every 3km of pipeline. Energy and communication networks were estimated as crossing over one of the sidewalks.

In the TD scenario, we modelled the mobility network, first, by measuring only the length of all streets using visual image analysis tool and, second, building road benchmarks to spatialize these linear measures. Considering that the ‘Campinas City Master Plan’ shows only two types of roads on campus (‘local’ and ‘collecting’), two road benchmarks (for ‘local’ and ‘collecting’ type of roads) were created based the minimum width requirements established by the ‘Campinas Master Plan’ and the ‘Law of subdivision, occupation and land use in the municipality of Campinas’. These legislations establish that ‘local roads’ must be at least fourteen meters wide (8m for motorized vehicle lanes and a 3m sidewalk in each side) and that ‘collecting roads’ must be at least eighteen meters wide (12m for motorized vehicle lanes and a 3m sidewalk in each side). Parking areas were calculated according to the number of parking spaces required for educational buildings established by the ‘Campinas Land Use and Occupation Law’. Lastly, datasets of complete networks were used to represent the water supply network, the energy distribution network and the sewer grid. Only the rainwater network was modelled as the MMurb scenario given that no dataset was available to represent it.

Embodied energy estimates used the material composition of each construction process found in the campus built environment listed in the Civil Construction Costs and Indexes Research National System (SINAPI) database.

Operational energy (B6), operational water (B7) and operational mobility (B8) used five different data sources (local, municipal, state, regional and national). Input energy and water consumption were normalized per capita, and results extrapolated for the campus population, accounted for in terms of full time equivalence factors. For operational mobility, we considered cars and buses modes of transportation (most common private and public transport modes used). We normalized both fleets per capita; extrapolated results for the campus population; and estimated total distance travelled over the life cycle of each type of vehicle based on average distance per trip, average number of trips per person, number of days travelling in a week, and allocation procedure (50% of impacts were allocated to the neighbourhood where the trip originated and 50% were allocated to the neighbourhood of destiny).

The only additional urban layer modelled at this time was food consumption (B9), which used two aggregation scenarios (local and national) considering rice, chicken and red meat intakes. The estimated number of meals served by the university restaurant per year (Monday to Friday, over 11 months) was normalized by the number of meals per person per day and multiplied by the campus population to find the total consumption.

Life cycle assessments

All foreground system LCI aggregation scenarios were then combined into five final representative scenarios (BU, MU, MM, MD and TD) and five neighbourhood LCAs were performed. Subsequently, a scenario uncertainty and a global sensitivity analysis were carried out.

RESULTS AND DISCUSSION

Urban layer impact contribution analysis

The building stock was responsible for roughly one to two thirds of the neighbourhood estimated impacts, considering the average of all modelling scenarios (**Table 2**). That would be about three times the impacts caused by urban infrastructure average figure (10,6%). Operational energy has the second largest contribution: 27,6% (being that 20% of impacts came from building stock use and 7,6% from public sector use). Mobility (18,3%) , food consumption (13,4%) also had important contributions, whilst operational water had a comparably minor share (0,92%).

Table 2 – Average impact contribution of each urban layer in the different scenarios modelled

| | BU Average | MU Average | MM Average | MD Average | TD Average | Total Average |
|--|---------------|---------------|---------------|---------------|---------------|------------------|
| Building stock | 35,7% | 3,9% | 1,5% | 43,2% | 62,2% | 29,3% |
| Urban infrastructure | 13,4% | 10,9% | 12,8% | 7,6% | 8,3% | 10,6% |
| Operational Mobility | 14,5% | 27,7% | 26,2% | 14,6% | 8,6% | 18,3% |
| Food consumption | 11,0% | 21,8% | 17,1% | 11,0% | 6,1% | 13,4% |
| Operational energy use (building stock) | 20,1% | 24,0% | 29,4% | 16,1% | 10,1% | 20,0% |
| Operational energy use (public lighting) | 5,0% | 10,2% | 11,3% | 6,8% | 4,5% | 7,6% |
| Operational water use | 0,2% | 1,6% | 1,8% | 0,8% | 0,2% | 0,92% |

Building stock

Finding show that the building stock was the main impact contributor in the three scenarios that considered the whole building material stock (and not only the envelope). In the BU scenario – modelled with the best data aggregation and that should consequently show the best result – it was responsible for more than one third of neighbourhood impacts (35,7%). This urban layer was also the main average contributor in several categories considered. It was responsible for 48,7% of abiotic depletion impact; 48,1% of marine aquatic ecotoxicity; 46,1% of human toxicity; 39,4% of eutrophication; and 35,5% of acidification potential. Furthermore, even when it was not the main contributor within an impact category, it showed significant contribution, such as: 36,3% in freshwater aquatic ecotoxicity; 23,7% in photochemical oxidation; and around 20% in primary energy, fossil fuel abiotic depletion and global warming potential.

When considering the scenario contribution per impact category, building stock impact stood out specially in the MD, BU and TD scenarios for the following impact categories: abiotic depletion (showing an impact contribution of 70% in the MD, 73% in the BU, and 95% in the TD scenario); marine aquatic ecotoxicity (63%, 74% and 95%); human toxicity (57%, 72% and 94%); freshwater aquatic ecotoxicity (41%, 51% and

86%); acidification potential (44%, 44% and 84%) and eutrophication potential (46%, 56% and 90%) in the same respective scenarios. All in all, these results highlight the need to prioritize the modelling of this urban layer whenever performing LCAs at the neighbourhood scale.

Urban Infrastructure

Urban infrastructure had a mid to low contribution in all scenarios and impact categories. Its average impact contribution varied from 8,3% in the TD scenario to 13,4% in the BU (**Table 2**). When considering the scenario contribution per impact category, its total average impact varied from 7,1% in photochemical oxidation to 22,6% in ozone layer depletion. Its lowest contribution impact per scenario was of 1,5% in abiotic depletion of the TD scenario and its highest contribution impact per scenario was 29% in ozone layer depletion of the BU scenario.

When comparing urban infrastructure absolute results per scenario, findings show that for some categories – such as renewable primary energy, freshwater aquatic ecotoxicity and terrestrial ecotoxicity, there is not much to gain by refining data aggregation. For other categories, on the other hand, such as global warming potential, abiotic depletion, photochemical oxidation and eutrophication, BU scenario presented a much higher impact.

In synthesis, results show that urban infrastructure should be considered in neighbourhood LCAs, but can be modelled with lower quality data (e.g. visual analysis) if resources and time are limited, seeing as it will represent around 10% of total impacts. However, whenever possible, a more refined data spatialization through geographic information modelling should be sought, as it will significantly impact some categories' results.

Operational Energy (B6)

The overall operational energy average impact was of 27,3%, from which 20% were due to building stock use and 7,6% due to the use in the public sector. In the MM scenario, this urban layer was the main average impact contributor and was responsible for 40,7% of impacts (**Table 2**). When considering all scenarios within each category, its total average impact showed highest values in the renewable primary energy category (38% for building stock and 14,1% for public use) and its lowest average impact were encountered in the abiotic depletion category (5,6% and 2,2% respectively).

Findings also show that this urban layer displayed a relatively lower variation between scenarios, especially for the public sector consumption. For the building stock energy use, there was a big gap between the BU and the rest of scenarios, which in turn behaved very similarly.

From this we can conclude that, as the building stock, the operational energy layer should be prioritized when performing a neighbourhood LCA as it will affect around 27% of total impacts; and that the building stock energy use should be modelled with the best spatialized data available (based on the actual neighbourhood consumption) for its significant impact contribution in the overall average and the public sector energy use can be modelled with lower aggregation data if necessary.

Operational Water (B7)

Operation water was the least impacting urban layer in all scenarios and all categories. Its contribution impact varied between 0,03% on terrestrial ecotoxicity of the BU scenario and 13,8% in abiotic depletion of the MM scenario. In all categories, operational water results showed that national, regional, state and municipal data greatly overestimated the neighbourhood water consumption in 70%, 96%, 92% and 103% respectively and that, even though a full-time equivalence factor was applied in the modelling process, it was not sufficient to represent the neighbourhood actual consumption amount. This is probably due to the exclusive educational use of the case study neighbourhood and to the fact that different city land uses may have significant different water consumption behaviours (e.g., residential use may have higher consumption due to showers and cooking; industrial use may have much larger consumption depending on the industrial process utilized; commercial use may have less consumption if only related to retail; etc.). These consumption behaviour differences are even more important in neighbourhoods that do not have mixed uses in their territory.

All in all, findings show that when resources and time are limited, operational water layer can be modelled with the lowest data aggregation (national average) as its impact contribution will be very low, however results will not be representative of the neighbourhood, especially in not mixed-use cases. For better representativeness, land use type is an input parameter that should always be considered.

Operational Mobility (B8)

As seen in **Table 2**, operational mobility was the third most impacting urban layer (18,3%). It was also the main impact contributor for several categories, such as: non-renewable primary energy, abiotic depletion fossil fuels, ozone layer depletion and photochemical oxidation.

When considering the impact contribution per scenario within each category, mobility total average contribution impact varied from 2,1% in terrestrial ecotoxicity to 50,7% in photochemical oxidation. Its contribution impact stood out in photochemical oxidation (varying from 21% in the TD scenario to 69% in the MU scenario), ozone layer depletion (ranging from 23% in the TD scenario to 41% in the MU) and abiotic depletion fossil fuels (varying from 14 to 32%, in the same respective scenarios).

When comparing mobility absolute results per scenario, findings showed a similar behaviour in all categories, that is, a MU and BU scenario with very similar results and a declining slope from MU to TD scenarios. This, however, occurred probably because data on the amount and average distance of trips per day (major parameters affecting the calculation) were only found in local scale (campus data) and national scale (ANTP). All things considered, results showed that this urban layer should also be prioritized when performing neighbourhood LCAs, as they represent an important share of total impact and have a huge impact on climate change. Thus, we find that at least municipal data should be sought for trips characterization.

Complementary Layers – Food Consumption (B9)

Although representing 13,4% of the total neighbourhood average impact, food consumption showed a low impact in most categories (ranging from 0,7% in abiotic depletion fossil fuels to 23,3% in eutrophication potential). Its major average impact was clearly in the terrestrial ecotoxicity category (62,3%); in that particular category, food consumption’s impact ranged from 45% (in the TD scenario) to 76% (in the MU scenario). Hence, this additional urban layer should be considered in neighbourhood LCAs whenever Ttox is a major concern.

Results Without any Complementary Layers

Finally, when comparing urban layer impact contributions without considering any additional layer (in this case, food consumption) findings showed that by considering the three most contributing urban layers (building stock, building stock operational energy and operational mobility) plus any other, results will represent more than 80% of neighbourhood LCA impacts (**Figure 2**). This corroborates with the above- mentioned prioritization and highlights a path to follow when time and resources are limited.

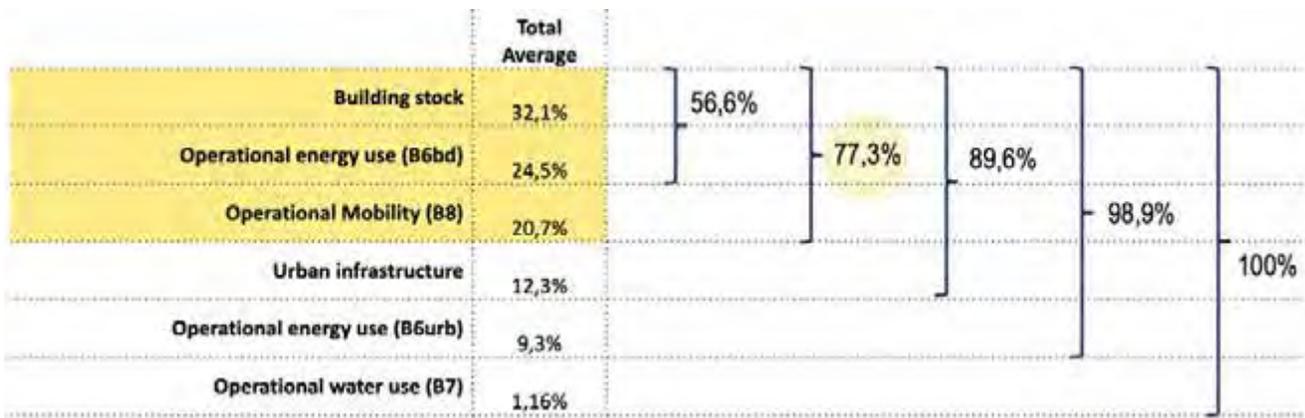


Figure 2 – Urban layer average impact contribution without additional layers

LCA STAGE AND BUILDING ELEMENT CONTRIBUTION ANALYSIS

The replacement stage (B4) was the main contributor to the total neighbourhood impacts (**Table 3**), followed by operational energy (being 20% of the impacts related to the built stock and 7,6% to public lighting), and by operational mobility (16,7%) and building products supply (A1-A3, 8,5%).

The replacement stage (B4) also had the higher average impact contribution for categories ADP, GWP, Htox, FWAtox, MAtox, Ttox, AP and EP, whilst operational mobility (B8) contributed the most for PEnr, ADPF, ODP and PO (29,6%, 29,6%, 38% and 50,4% respectively), and building stock operational energy (B6bs) contributed with 38% of the PEr impact.

Table 3 – Impact contribution of life cycle stages per neighborhood LCA layer, for the different modelling approaches tested

| | BU Average | MU Average | MM Average | MD Average | TD Average | Total Average |
|---|------------|------------|------------|------------|------------|---------------|
| A1-A3 - Product Stage | 6,2% | 5,5% | 4,2% | 18,3% | 8,5% | 8,5% |
| A4-A5 - Construction Process Stage | 2,0% | 2,1% | 2,0% | 4,3% | 2,0% | 2,5% |
| B2 - Maintenance | 0,2% | 0,7% | 0,7% | 0,2% | 0,0% | 0,4% |
| B4 - Replacement | 52,0% | 30,9% | 27,1% | 38,4% | 65,7% | 42,8% |
| B6 - Operational Energy Use (building stock) | 20,1% | 24,0% | 29,4% | 16,1% | 10,1% | 20% |
| B6 - Operational Energy Use (public lighting) | 5,0% | 10,2% | 11,3% | 6,8% | 4,5% | 7,6% |
| B7 - Operational Water Use | 0,2% | 1,6% | 1,8% | 0,8% | 0,2% | 0,9% |
| B8 - Operational Mobility | 13,7% | 24,6% | 23,1% | 13,5% | 8,4% | 16,7% |
| C1-C4 - Deconstruction Process Stage | 0,6% | 0,5% | 0,4% | 1,6% | 0,6% | 0,7% |

The average shares of the overall neighbourhood impacts were: operational energy (27,6%), building services - water, sewer, energy and communication networks (20,2%), operational mobility (18,3%) and food consumption (13,4%). If only the embodied energy is analysed, the building services are followed by the mobility network (8,2%), roofing (2,6%) and finishings (2,4%).

SCENARIO UNCERTAINTY AND SENSITIVITY ANALYSIS

Seven impact categories were chosen to undergo scenario uncertainty and global sensitivity analysis as they were representatives of the others [19]. The replacement stage (B4) of the building stock, showed the largest variance (61,4%, **Table 4**), followed by operational energy (10,4%), building products supply (10%) and operational mobility (9,6%). Food consumption displayed a high variance in terrestrial ecotoxicity category and urban infrastructure replacement stage (B4) a total average variance of 2,9%.

Combined with the impact contribution analysis, these findings highlight the data modelling fronts that require extra care regarding data quality and parameter uncertainty analysis: building stock replacement stage; operational energy; and operational mobility; as they show high overall impact contribution and higher variance. Performing parameter uncertainty analysis is a daunting task at any scale, but can be specially challenging due to the massive amount of data processed when assessing neighbourhoods. But LCA practitioners can streamline parameter uncertainty analysis to urban layers in which few parameters greatly contribute to impacts, such as operational energy and mobility. Finally, even if parameter uncertainty cannot be performed at all, scenario uncertainty analysis combined with a global sensitivity analysis comes handy to show where practitioners should return and refine data.

Table 4 – Estimated variance of impact categories for the neighbourhood LCA layers

| | PE _{nr} | PE _r | GWP | ODP | FWA _{tox} | T _{tox} | PO | Average |
|---------------------------|------------------|-----------------|-------|-------|--------------------|------------------|-------|---------|
| Building stock (A1-A3) | 5,9% | 39% | 12,6% | 9,5% | 0,7% | 0,9% | 1,2% | 10,0% |
| Building stock (A4-A5) | 0,8% | 0,4% | 1% | 2,2% | 0% | 0% | 0% | 0,6% |
| Building stock (B4) | 61,7% | 50,8% | 50,4% | 18,6% | 98,7% | 60,2% | 89,6% | 61,4% |
| Building stock (C1-C4) | 0,2% | 0% | 0% | 0,5% | 0% | 0% | 0% | 0,1% |
| Urban infrastructure (B4) | 3,1% | 0% | 7,1% | 9,8% | 0% | 0% | 0% | 2,9% |
| Operational Energy (B6) | 14,5% | 8,7% | 24,9% | 17% | 0,5% | 6,4% | 0,5% | 10,4% |
| Operational Mobility (B8) | 13,7% | 1,1% | 2% | 42,1% | 0% | 0% | 8,5% | 9,6% |
| Food consumption (B9) | 0% | 0% | 1,7% | 0% | 0% | 32,4% | 0% | 4,9% |

CONCLUSIONS

When performing a neighbourhood LCAs, practitioners should always target to find the best data available for each urban layer, however, in view of the amount of data required, the systemic complexity intrinsic to the scale and the frequent resource/time limitations, some prioritization might be needed. Results show that the three urban layers that should be prioritized in neighbourhood LCAs in terms of their inclusion in the scope are the building stock, the operational energy and the operational mobility, due to their significant impact contribution in the overall average. For the operational energy layer, practitioners should seek the best spatialized data available (based on the actual neighbourhood consumption) for the building stock energy consumption (B6bs) and can use lower aggregation data for the public sector energy use (B6urb). For the operational mobility layer (B8), at least municipal data should be sought for trips characterization. By including these three urban layers in the scope plus any other layer, results will represent more than 80% of neighbourhood LCA impacts.

When resources and time are limited, the urban infrastructure layers should be considered in neighbourhood LCAs, but can be modelled with lower quality data (e.g. visual analysis) as it will represent around 10% of total impacts. Nevertheless, whenever possible, a more refined data spatialization through geographic information modelling should be sought, because it will significantly impact some categories' results.

Operational water layer can be modelled with the lowest data aggregation (national average). Results will not be representative of the neighbourhood, especially for not mixed-use cases, but from our findings, its impact contribution would possibly be low (around 1%). For improved representativeness, land use type is an input parameter that should always be considered.

Although representing 13,4% of the total neighbourhood average impact, the complementary layer of food consumption showed a low impact in all categories but terrestrial ecotoxicity, in which this layer stood out with a 62,3% contribution. This urban layer should be considered in neighbourhood LCAs especially when Ttox is a major concern.

In terms of the LCA stages, replacement of building parts (B4) was responsible for an average of 42,8% of neighbourhood impacts and thus should always be considered in the neighbourhood LCAs. Operational energy and mobility came in second and third, but their important contribution has already been emphasized. Finally, product stage (A1-A3) should also be considered whenever possible as it is responsible for 8,5% of impacts. As to building elements, building services (20,2%) should always be included in the assessments, hence, envelope-only scenarios should be used only if considering a benchmark factor to represent the building services, e.g., per m², otherwise, results can be misleading. In terms of embodied impact, mobility network (8,2%) also stands out, followed by roofing (2,6%) and finishing (2,4%).

Performing parameter uncertainty analysis can be a daunting task at any LCA scale. Scenario uncertainty analysis combined with a global sensitivity analysis seem to suffice for the scale in question, as it will show where practitioners should return and refine data collection. But if parameter uncertainty is pursued, practitioners are advised to focus on the urban layers in which few parameters contribute to most impacts. Our uncertainty and sensitivity analysis show that building stock replacement stage, operational energy and operational mobility are the LCA components to be attentive to, for their high contribution to both impacts and variance.

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A CRADLE TO CRADLE-INSPIRED PATTERN LANGUAGE FOR CIRCULAR URBAN AREAS

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This work has been supported by CAPES, the Brazilian Coordination for the Improvement of Higher Education Personnel (LG is funded by CAPES Social Demand Program grant #88882.435514/2019-01), and CNPq (National Council for Scientific and Technological Development (VG is funded by Research Productivity grant #306048/2018-3)).

ABSTRACT

Urban areas place the most intense connection among people and nature, and they are a key factor for the transition from a linear to a circular economy (CE). But, in the quest for managing urban areas towards CE, different meanings, approaches, and methods have been devised. The overall research goal is to develop a tool for applying the CE concept to urban areas, while allowing urban managers to replicate and transfer criteria, design patterns, and requisites to different scenarios. To this end, this paper focuses on (i) exploring the main urban qualities of circular urban and (ii) setting bases for a *Pattern Language for Circular Urban Areas* complemented by a set of assessment criteria to measure and monitor improvement during design development or over time. The Pattern Language forms a network of interconnected good design practices to assist in replicating and transferring requisites, criteria, and design patterns applicable to different urban contexts. Our research exposed that designing and planning urban environments to CE should reflect nature's functioning. For that, the analyzed urban areas should be assessed in regarding three complementary qualities, that is: how (1) Regenerative; (2) Distributive and connected; and (3) Local oriented they are. A Cradle to Cradle framework was used to define circularity dimensions to achieve those qualities in different urban contexts and connect patterns and related metrics. As a result, the concept of a *Pattern-Language for Circular Urban Areas* is herein illustrated.

KEYWORDS

Circular urban areas, Circular economy, Cradle to Cradle, Regenerative urban systems, Pattern Language, Wholeness

INTRODUCTION

Urban areas place the most intense connection among people and nature, and they are a key factor for the transition from a linear to a circular economy (CE). Cities have been filled with a linear production-consumption system, and our choices on urban issues, e.g., transportation, food, construction material, sanitation, and energy, directly impact on ecosystem services and climate [1]. Shifting from a damaging, anthropogenic-dominant, and nature destructive society to a regenerative model that meets CE fundamentals requires a new world view and a different approach to sustainability.

For that, we should consider the concept of ‘*the whole*’ and the fundamentals of ‘*wholeness*’ [2], in which the universe, the biosphere, the biotic and abiotic matter constitute a complex unity of networks, an organized coherent system of many parts fitting and working together as one. This major shift acknowledges that we, as humans, are part of nature and not above it; therefore, we should evolve from simply minimizing activities that are degenerative to the environment towards maximizing those that restore and regenerate ecological systems [3] (Figure 1). And urban systems, like any other nature’s ecosystem, are themselves organized as patterns and are part of a larger interconnected complex unity of different systems and parts, i.e., ‘*the whole*’ [2]. Hence, a pattern language structure ensures designing urban areas as living systems. These patterns form networks, and the networks form a pattern language that is constantly being altered and complemented. Each pattern describes a problem and in sequence designates a solution to that problem, which can be used infinite times [4].

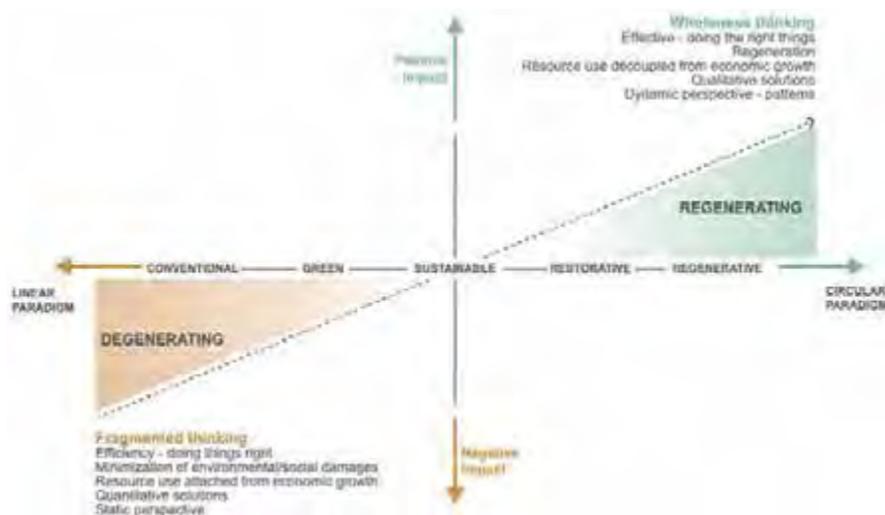


Figure 1 - Evolving from linear to circular paradigm towards regenerating systems – from fragmented to wholeness thinking. Modified from [5].

Furthermore, our Systematic Literature Review (SLR) exposed that the complexity of urban dynamics in response to powering CE in urban environments should be based on nature’s functioning into our planning and design processes. The SLR also raised existing concepts, categories and indicators being used in recent literature on circular urban areas. In this study, Cradle to Cradle (C2C) approach and principles [6] stood out from other CE approaches in coping with the complexity of urban dynamics, as the three C2C design principles are inspired by nature’s functioning and can embrace the multiplicity of qualitative and quantitative requisites needed for developing tools for applying CE to urban areas [7]. Thus, a pattern language based on C2C principles can express patterns that function according to nature’s dynamicity, connecting different levels of scale to form a ‘*Pattern Language for Circular Urban Areas*’.

The objective of the research is to develop a tool for applying the CE concept to urban areas, that would ideally support urban managers to replicate and transfer requisites, criteria and design patterns to different study contexts and scenarios. Thus, this study aims at (i) exploring the main urban qualities of circular urban areas and (ii) setting bases for a *Pattern-Language for Circular Urban Areas* formed by a network of interconnected patterns or good design practices. The Pattern Language would be then complemented by a set of assessment criteria to measure and monitor improvement during design development or over time.

METHODS

Firstly, we carried out a Systematic Literature Review (SLR) based on Kitchenham [8] to understand the main categories and indicators of CE applied to urban areas on existing theoretical frameworks. As a result, 13 categories and 104 indicators emerged from the C2C framework [7].

The SLR sample was scrutinized by posing the following research questions: “What are the main qualities that we should intend when developing circular urban areas?” and “What are the patterns and proxies needed for urban systems to develop, replicate and evaluate circularity?”. After title and abstract filtering, we analyzed 35 articles according to their understanding of CE applied to urban areas, and we categorized three complementary qualities needed for developing circular urban areas.

Finally, for applying these qualities to circular urban environments, we developed qualitative research based on documental analyses. The SLR sample was complemented by using the ‘snowball’ technique. Existing evaluation systems for sustainable urban areas were also examined for insights on proxies and indicators, as well as a recent application of Alexander’s seminal pattern language structure [4] to sustainable development [3]. A draft ‘*Pattern Language for Circular Urban Areas*’ was then mapped, with its first patterns and indicators or proxies (Figure 2).

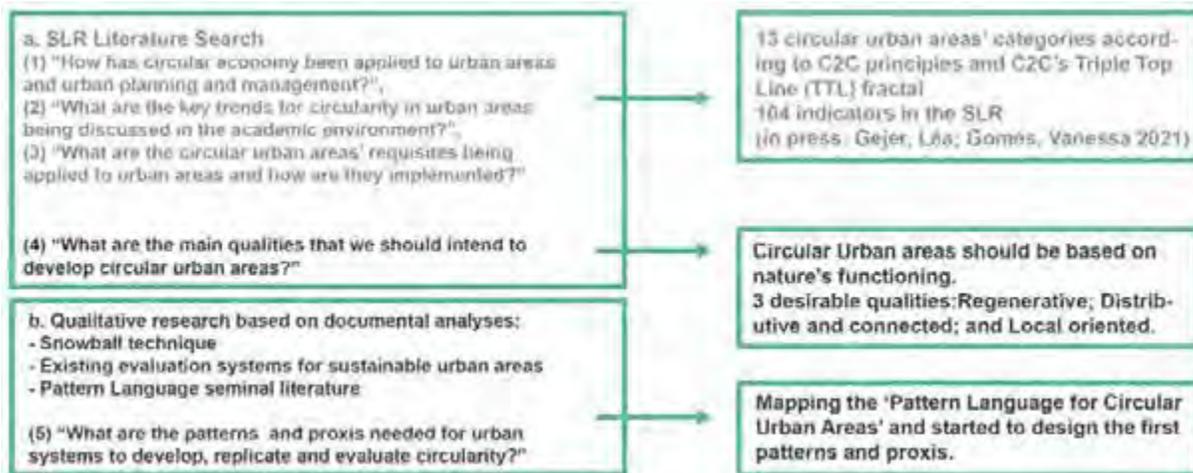


Figure 2. Research Methods.

RESULTS AND FIGURES

Circular Urban Qualities

The SLR showed that, when considering applying CE to urban environments, design and planning should be based on nature’s functioning. For that, the analyzed urban areas should be assessed in regarding three complementary qualities, that is: how (1) Regenerative; (2) Distributive and connected; and (3) Local oriented they are. These qualities are further discussed in the following sections.

Regenerative features

Urban Ecology proposes a simple model for nature-and-people interaction, pointing out how nature and people affect each other positively and negatively (Figure 3). In the current structure of society, people affecting nature represent the strongest interaction - and therefore that of the most concerning - for generating overall negative effects and inhibiting beneficial development of society and nature. With more than half of the population currently living in urban areas, their ecological footprints cover much of the Earth’s surface, and urban energy use is a relevant factor of climate change [1].

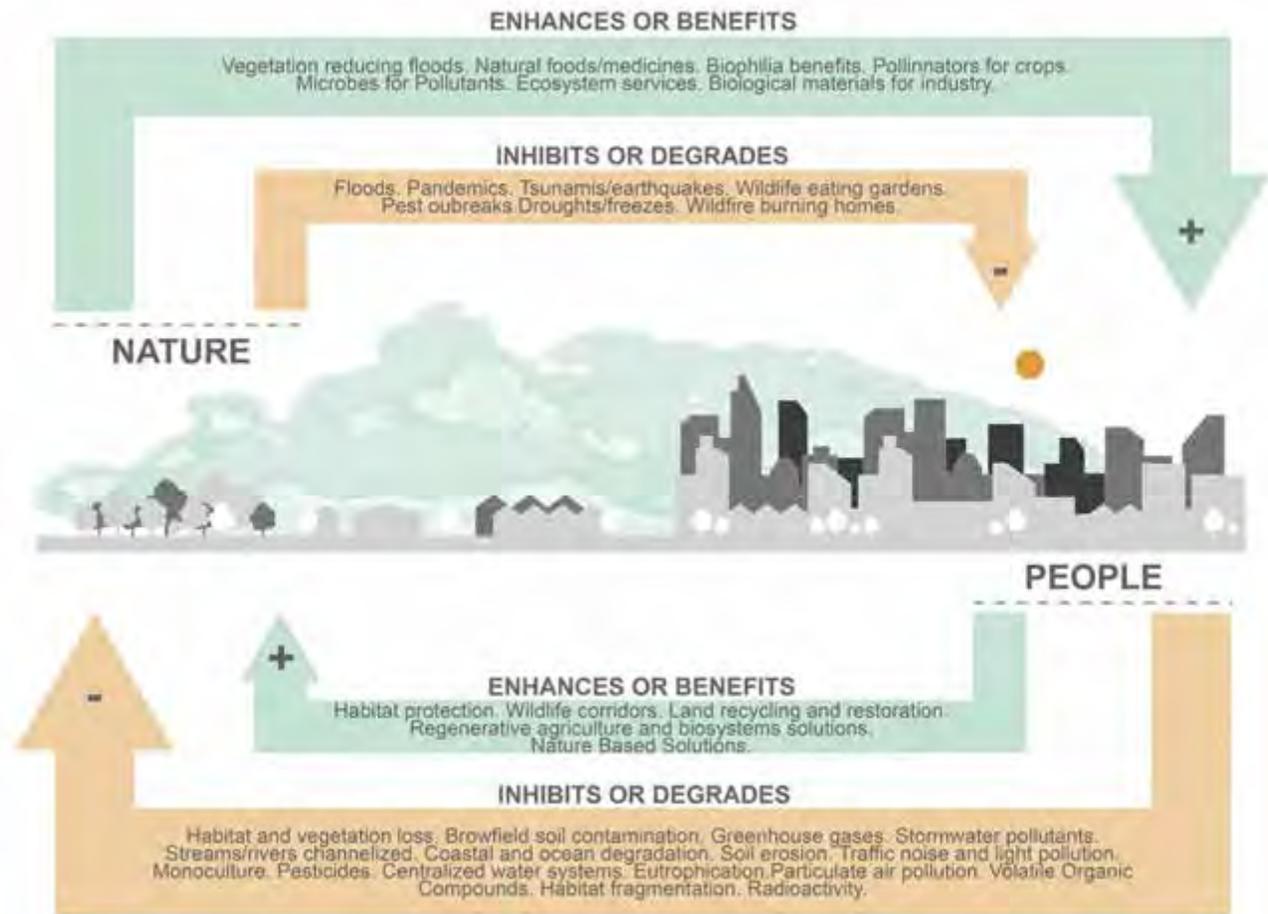


Figure 3. Urban Ecology model for nature-and-people interaction. Adapted from [1].

The challenge we now face is to create regenerative urban areas, assuring that they do not only become resource efficient and low carbon emitting, but rather positively improve the ecosystem services they receive from beyond their boundaries. Thus, regenerative urban areas provide a surplus of positive effects that would overcome the total negative effects in that urban area and related nature. These areas should improve systems' capability to provide conditions for urban fabrics, biosystems and cultures to restore, renew and revitalize, while actively supporting regeneration of natural systems from which they draw resources.

Distributive and connected features

Urbanization is a spatially grounded social process, which encompasses a range of actors, with different objectives and commitments, and which interact through a specific configuration of intertwined spatial practices. There is always a relationship amid social processes and artifacts (e.g., constructed forms, produced spaces, infrastructure) organized in a specific spatial configuration. This creates a permanent tension between processes and forms, or between activities and things, resulting in a chronic instability of these spaces [9]. This also reflects on social and economic attributes, as the poorest areas are often the most vulnerable and with less access to environmental and urban services and infrastructure [10].

Thus, being distributive refers to dispersing and circulating created value instead of concentrating them. These economies should be designed to naturally form a distributed network whose many nodes, larger and smaller, are connected, as in a web of flows, or as in nature's networks. These networks are structured by branched fractals, ranging from a few larger ones to many medium-sized ones, to a myriad of small ones, imitating the structures of, for instance, rivers tributaries, branches of trees, blood vessels in the body, or the veins of a leaf. Resources such as energy, matter, and information can flow through this network to achieve a fine balance in the system [11].

Distributing resources and diversity of systems and activities provides conditions for system's efficiency and resiliency in a circular city. The interconnected dots form hubs of CE activities and projects benefiting local communities. Urban areas are intrinsically connected to other systems as they exchange materials and energy with areas outside urban limits to maintain internal levels of complexity, organization, and functionality; thus, low entropy systems should be also addressed to interconnect a network of natural systems providing a diversified array of urban ecosystem services to the urban socio-ecological system [12]. Therefore, the effectiveness of a system depends not only on the system itself, but in its interrelation with other systems beyond its boundaries.

Local oriented features

Implementing CE in urban areas depends on specific local potentials, e.g., resource availability, geophysical aspects, and local needs. Harvesting local resources and closing metabolic loops encourage CE practices and regenerate local natural capital, especially by providing powerful motivation for changing social practices, lifestyles, and systems of provision. The emergence of local business, industry, and financial institutions increases economic self-reliance, promotes local environmental protection, and builds local human capital [13]. Moreover, features inherent to urban neighborhoods and districts areas, e.g., physical proximity, complexity, and connectivity, facilitate resource cycling due to relatively short distances, and possible common investments in a community [14].

Locality also refers to local knowledge, which creates appropriate solutions for the protection of natural capital through managing local resource availability, physical environment, and social and cultural practices [13]. Exploring local potential fortifies diversity in the form of biodiversity, increasing systems' resiliency and regeneration, and of multiculturalism, which can be especially powerful to emerging economies to explore the enormous potential of contribution of native peoples to reconstruct our relationship with land and its resources.

Finally, a local oriented project relates to its land use decisions, which implies the assessment for urban services, like housing, employment, transportation, nature, etc. Although land often symbolizes a valuable resource in cities, wealth production derived from valuable land does not represent the quality of the soil, but the location itself. Its greatest investments return as urban commercial and residential developments, and no longer from agriculture. Real estate development produces a tangible product that has immediate social consequences which come from the fixed nature of the land and the materiality of the built environment [15]. Land offers ecosystem services which are essential for regenerative processes in cities, e.g., urban agriculture, recycling industries, water management infrastructure, etc. Thus, land which remains vacant because of the cost of decontamination or speculation is a waste of a valuable resource, while land recycling should be facilitated to optimize resource use. However, often those activities are considered to be low-value activities while requiring space within cities, and therefore should be incorporated for directing circularity to urban areas [13].

New framework for circular urban areas

A framework for circular urban areas aims at providing a systemic vision and methodology to engage stakeholders at the city level into the transition for CE. Its purpose is to support urban planners, urban developers, and public administrators to design or transform urban areas into regenerative systems, while coping with intensified cities' land use and climate pressures, and technical and local aspects. The Pattern Language will guide urban planners and stakeholders throughout the planning process for co-creating of communities, neighborhoods, and districts supplied with renewable energy systems, universal sanitation, healthy land, clean water, and fresh air.

To cover the three complementary and interrelated qualities for circular urban areas that emerged in our SLR: regenerative; distributive and connected; and local, the framework should embrace diverse knowledge fields that comprehend the totality of interconnected and dynamic urban issues, requiring both qualitative strategies and quantitative tools for its implementation and continuous improvement, while mirroring nature's functioning. For that, the Cradle to Cradle framework [6] was applied to determine circularity dimensions that can be expressed in urban systems. Based on these categories, the main patterns for a *Pattern Language for Circular Urban Areas* were mapped and combined with indicators.

Cradle to Cradle framework

Cradle to Cradle (C2C) framework conducts human systems' design through mimicking nature's intelligence by following its three principles: (1) waste is food: designing circular water, energy, and nutrients systems, distinguished into healthy biological and technical cycles; (2) use current solar income: operating renewable energy sources in its maximum potential; and (3) celebrate diversity: exploring beneficial local conditions, materials, and cultures.

Furthermore, to design eco-effective solutions, C2C's authors propose the Triple Top Line (TTL) perspective that was firstly developed for C2C business models in opposition to the Triple Bottom Line triangle, from which application has been criticized by the authors for being a balancing act between competing interests (economic, social, and environmental) to minimize footprint. In contrast, the TTL develops opportunities to impulse each of them. The fractal represents an infinitely interconnected world, predicting beneficial relationships rather than inherent conflicts. Human interests are settled in its center demonstrating how each design decision impacts on each vertex. The TTL supports planning a product or system, moving around the fractal, and investigating how the project can generate value in each category. The objective is to maximize value in all areas of the triangle, rather than balancing different perspectives.

To provide a systemic vision and methodology to engage local features and stakeholders at the urban level into the transition for a CE, we advanced in our hypothesis verification for structuring CE implementation to urban areas. The requisites and indicators presented in the SLR were grouped into the three C2C principles, while adapting C2C categories from buildings' design application to urban disciplines. To this end, TTL fractal has ensured that all intended areas of the fractal (ecology, equity, economy) in an urban spatial context are being covered and their values are maximized. This resulted in thirteen categories that comprehends the basic interest areas when applying CE into urban spatial practices [16] (Figure 4).



Figure 4 - The framework structure: the three C2C principles in the inner circle (waste is food, use current solar income, and celebrate diversity), and the TTL fractal (economy-ecology-equity) representation in the outer circle. In the between, the thirteen categories of circularity in the urban context [7].

Pattern Language

The *Pattern Language for Circular Urban Areas* follows a similar structure of the Pattern Language developed by Alexander et al. [4]. A typical pattern language is a process of describing and organizing a set of patterns, or good design practices within a field of expertise. In this context, the *Pattern Language for Circular Urban Areas* provides a set of patterns in a useful, organized way to guide urban development practitioners for the transition and development of circular urban areas. Furthermore, it will be complemented with indicators for assessing, reviewing, and improving circular processes and systems described in the patterns.

Recently, Roös [3] has complemented Alexander's work by proposing a "Regenerative-Adaptive Pattern Language", inspired by ecosystem models. The author has created twelve fundamental patterns to face global society critical issues through regenerative and adaptive solutions. Two of those patterns underpinned the structure for *wholeness* and spatial regeneration concepts. The first of them is the "Notion of Regenerative-Adaptive Patterns", which gives directives to navigate through the complexities of the pattern language. The second pattern is 'The Whole', which describes the current issues of the planet and argues towards ways to progress to a regenerative-adaptive future.

The *Pattern-Language for Circular Urban Areas* is mapped in five hierarchical levels (Figure 5):

- i. Two adopted Patterns from the Regenerative-Adaptive Pattern Language from Roös [3]: 'The Whole', and the "Notion of Regenerative-Adaptive Patterns", which give a holistic view of the pattern language and the wholeness.
- ii. C2C Principles to guide human systems' design through mimicking nature's functioning [6].
- iii. C2C categories for circularity in the urban areas [7].
- iv. Requisites to guide design and planning strategies for achieving the desired qualities.
- v. Indicators and proxies for assessing, reviewing, and improving circular processes and systems described in the patterns.

Patterns

A pattern language is structured as a directed acyclic graph, with each node representing a pattern. Edges pointing away from a pattern are its consequences, showing which lower levels of patterns need to be applied next, establishing a hierarchy within the relationship of different patterns. Hence, a pattern language gives each person who uses it the power to create an infinite variety of buildings, towns, and regions just as an ordinary language gives us the power to create an infinite possibility for building sentences [2]. To breed such a power, each pattern of the *Pattern Language for Circular Urban Areas* tracks a similar structure to that of Alexander's Pattern Language and it sets out as follows (Figure 6):

- Title of the Pattern
- Upward pattern links with 'higher' patterns or of key knowledge
- Three stars (***)
- One picture or representative image that illustrates the overall message of the pattern
- Introductory paragraph
- Headline (bold): essence of the problem
- Body of the problem
- Solution (bold): what requires solving the problem. It has an instruction format
- Diagram: solution and components, a sketch with simple notes expressing the solution
- Three stars (***)
- Downward pattern links with 'smaller' patterns, indicators or proxies needed to fulfill the pattern.

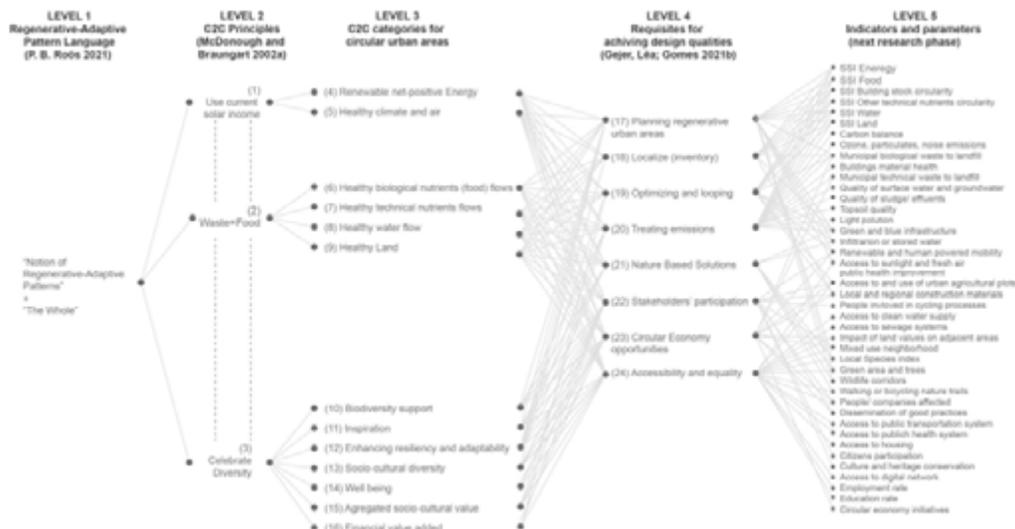


Figure 5. Pattern-Language for Circular Urban Areas' Map, with five pattern levels.

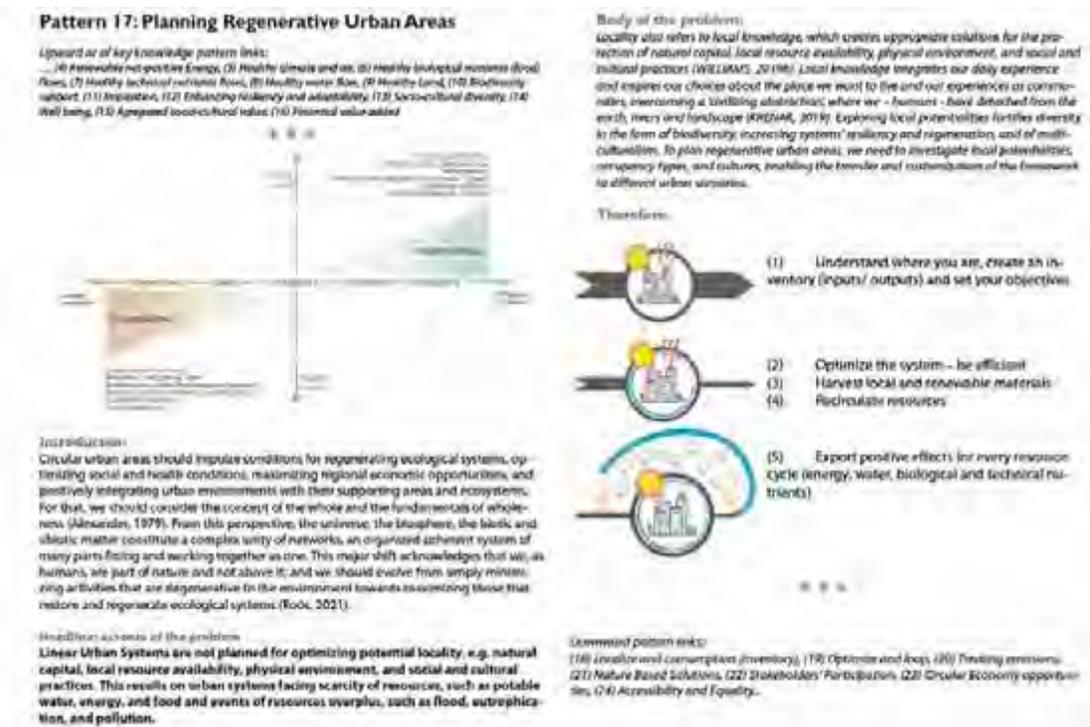


Figure 6. Example of a pattern from the Pattern Language for Circular Urban Areas.

DISCUSSION

To develop a design and evaluation framework for supporting urban practitioners through the transition for circular areas, we first explored a critical literature review to raise the main qualities for applying CE to the urban context. We concluded that to target the complexity of CE fundamentals applied to urban dynamics, we should ground our design strategies on nature's functioning. Based on that, three complementary circular urban qualities emerged from our SLR: (1) Regenerative; (2) Distributive and connected; and (3) Local oriented. To achieve these qualities, we applied the C2C principles and TTL fractal to establish categories for circular urban systems, mapped the main patterns for the *Pattern Language for Circular Urban Areas* and combined them with indicators, resulting in five hierarchical levels of patterns. As a result, this Pattern Language will form a network of organized and interconnected good design practices to guide design, implementation, and evaluation of CE to the urban environment, that will enable urban managers to replicate and transfer criteria, design patterns and requisites to different urban contexts.

One of the main difficulties of designing such complex and dynamic urban areas is that it requires connection of multiple spatial practices, strategies, and action tools, which are currently disconnected. The *Pattern Language for Circular Urban Areas* connects qualitative directives and strategies for co-creating circular solutions in urban areas and quantitative features, which enable the evaluations and improvement of these patterns and urban systems. Innumerable indicators and proxies can be developed for such complex issues; therefore, in the next phases we are going in deep in the design of each pattern, and indicators, which may need a variety of proxies to achieve a more coherent unity for the pattern language. These indicators and proxies need to be calibrated to complement metrics and to describe best practices for circular urban areas.

Hence, this paper contributes to the discussion of how the C2C approach combined with the Pattern Language structure can equip urban practitioners with elements to design and evaluate CE systems in urban areas, while representing nature's functioning to urban design and planning. It links different existing perspectives from literature and provides an initial structure which will be further detailed for creating an array of qualitative and quantitative requisites needed for addressing and implementing CE to urban areas. The main challenges ahead are to balance adherence to local urban features while being flexible for being transferred or adapted to other contexts; to manage interactions with other locations or regions outside the studied areas' boundaries; to encompass diverse social structures focusing on citizen empowerment; and to develop an integrated long-term vision incorporating multiple actors and nature.

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URBAN ECOSYSTEM ASSESSMENT FOR THE CITY OF CÁDIZ AN INTEGRATED METHODOLOGY FOR URBAN AND ENVIRONMENTAL MANAGERS

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ABSTRACT

Coastal cities are suffering an accelerated growth that will continue in future decades, putting intense pressure on urban ecosystem services. Studying urban areas as social-ecological systems and developing analytical frameworks allows understanding a complex network of relationships between anthropic and natural variables. Nonetheless, an integrated, efficient and applicable framework that will facilitate the implementation of Ecosystem-Based Management principles for urban management is not yet available. This research integrates a series of tools and frameworks like the SES Framework, the DPSIR and remote sensing techniques to identify and determine the state for urban ecosystems services. This methodology allowed the description and identification of urban ecosystem services and described in detail the characteristics and relationships of the social-ecological system in Cádiz. It also determined the main drivers and pressures over the urban ecosystem services. Additionally, it measured the state's change using remote sensing techniques like the Normalised Vegetation Index for urban vegetation, Chlorophyll and Total Suspended Matter for water bodies and NO₂ as an indicator of atmospheric pollution. Finally, considering the gathered information, this research proposed a series of responses based on the Ecosystem-Based Management principles. This integrated methodology has proven to be an efficient, relatively simple, and beneficial technique for urban and environmental managers looking for more sustainable and resilient cities.

KEYWORDS

INTRODUCTION

The coastal zone is a particular area where there is an interaction between land and sea; therefore, many subsystems interact, creating interdependent interactions and relationships [1]. If a city is localised in this area, the interactions and relationships can become more complex. Cities are considered social-ecological systems due to their intricate interactions with users and other ecosystems. Consequently, coastal cities are structured from several social-ecological systems in a narrow fringe of geographic space [2].

This complex system provides a combination of historical, cultural, geographic, and economic conditions that are attractive for human settlements, for this reason, 40% of the world's population lived in 2129 cities or urban centres less than 100km away from the coastline [3]. Consequently, this phenomenon increases coastal migration and urban footprint growth, provoking pressure in coastal resources and ecosystems that can reduce the supply of Ecosystem Services (ES), deteriorating human well-being [4]. The presence and growth of urban agglomerations require a steady supply of resources and goods to ensure human well-being. These ES can be imported from other regions or have human-made alternatives to some extent. Nonetheless, urban ecosystems provided some irreplaceable ES [3], [5].

Due to the complicated relationship between the population, the city infrastructure, government institutions, private stakeholders, and the urban ecosystems, it is necessary to apply a management approach that collates all the interactions and relationships. Ecosystem-based management (EBM) is a method that moves away from a single species or sector management approach to a more complex understanding of the interactions in a specific environment therefore, EBM has to oversee human activity to maintain ES by restoring or preserving habitat quality[6].

This research has the objective to offer an understandable, resourceful, and replicable methodology that would facilitate the introduction of the EBM principles into policies, urban plans or projects. It aims to assist urban and environmental managers in the practical assessment of urban ecosystem services to understand the relationship between human well-being and the environment inside and surrounding a city's boundaries.

METHODOLOGY

The methodology was developed under the EBM approach for managing human activity to conserve the ES found in coastal cities. It corresponds to a combination of the following frameworks:

- The Social-Ecological System Framework facilitates the definition of boundaries of the coastal cities and describes the cities' different aspects and interactions.
- A variation of the Driver-Pressure-State-Impact-Response Framework will identify the main drivers of change and their effects on each city.
- ES identification and measurements using remote sensing and geographical information system tools.

To determine the study area as a Socio-ecological System Framework (SES):

A social-ecological system has interactions between social and ecological units that are mutually dependent and intertwined at multiple scales. It includes defined resources and the necessary entities for its management [7].

The SES framework comprises variables representing the subsystems and the primary system interactions (Table 1)[8]. These variables also have sub-variables composed of specific indicators, allowing a system's characterisation at multiple scales. The variables and sub-variables in the SES framework can predict the outcomes according to their sustainability, representing the system's social and ecological characteristics.

The SES framework is a diagnostic tool to determine a system's sustainability based on its human impacts. Therefore it has an anthropocentric orientation. This framework helps identify the stakeholders and their main drivers for impact on the common pool resources (CPR); therefore, it can be an asset for other frameworks and environmental management plans.

The SES can characterise very complicated systems like urban coastal areas. In this case, unfortunately, the boundaries between ecological (different ecosystems like the coast, mangroves, forest, urban, and other ecosystems.), administrative (different municipalities, counties, provinces, regions, and different governmental divisions), and socio-economic units (industries, commercial use and other economic or social sectors) are seldom the same producing a governability conflict affecting the CPR and therefore the well-being of the stakeholders. This research follows these criteria to analyse the city as an SES Framework (Table 1):

Table 1. Definition of the SES Framework for this research

| SES Subsystems (variables) | Description (sub-variables) |
|---|---|
| Resource System | The city of Cádiz is SES under study. Therefore, the resource systems include the urban and natural systems found in the selected geographical area. The main economic sectors must be identified, the system's boundaries established, the area and the population quantified, and the city's facilities located. |
| Resource Units | Because this research aims to monitor urban ES, the resource units are all the ecosystems and the ES inside the resource system. For the identification of the ES, this research uses the Common International Classification of Ecosystem Services (CICES) from the European Environment Agency (2018) and the Millennium Ecosystem Assessment (2003). |
| Governance system | Because this research aims to provide urban planning tools, the governance system will focus on urban planning and spatial plans. |
| Users | The users are the population and visitors of a given city. |
| Related ecosystems | Related ecosystems are closer than 10km from the city's defined geographical boundary. This boundary is defined as the area the user can quickly mobilise for the related ecosystems enjoyment. |
| Social, economic, and political settings | National and regional politics and strategies that can affect urban planning and the conservation of urban ES |

SES geographical boundaries

This research considers The Coastal Social-Ecological System (CSES) conceptual framework described by de Andrés et al. (2017) for the study areas' delimitation, precisely the definition of shoreland as a geographical boundary for the urban area with oceanfront. Resources found in the *Sistema de información de Ocupación de Uso del Suelo de España SIOSE* (<https://www.siose.es/>) from the National Geographic Institute of the Spanish Government and Sentinel 2 imagery were used to establish the urban footprint and the geographical boundary of each city.

To identify drivers and pressures of change in the study area

The DPSIR framework can clarify the interactions between ecosystems and human influence in an SES like a city. It has the advantage of being proficient at any scale, from global to sub-catchment or in specific sectors [11]. The framework analyses the drivers, pressure, state, impact and responses of a specific system, emphasising the causal relationship and interactions between them [12]:

One variation on the DPSIR model is the Ecosystem-Based Management-Drivers-Pressures-State-Ecosystem Services-Responses (EBM-DPSER) proposed by Kelble et al. (2013). The EBM-DPSER modifies the framework to focus on the ES variation and causal relationship between human society and the ecosystem state.

Kelble et al. (2013) based this variation of the DPSIR model on the Ecosystem-Based Management (EBM) approach through the principles of interaction between biophysical and human components, the dependency of society on ES, and the impacts that human activities have on different ecosystems. According to Kelble et al. (2013), EBM changes the focus on short-term economic benefits or environmental conservationism for the ecosystem's long-term capacity to provide a wide-ranging set of ES that will improve human well-being. Kelble et al. (2013) propose to exchange the module of impacts for ES, for which the definition will vary from the "variations in human well-being due to the influence of the state change" to "variations in ES due to the influence of the state change."

To measure the state of the urban ecosystems and their ecosystem services

For the following stages of the EMB-DPSER framework and to define the state of the ecosystems and their ES, remote sensing techniques are of great utility due to the spatial qualities of urban planning and ecosystem mapping [13].

Among the most used remote sensing techniques for ES mapping is land use, the Normalised Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Leaf Area Index (LAI) are measurements broadly used to monitor ES [14]. For this research, NO₂ indicator for atmospheric emissions, NDVI and water quality indicators (Chlorophyll-a and Total Suspended matter) were selected to monitor the state of the ES in the city of Cádiz.

RESULTS

SES analysis of the urban area.

The following sections summarise the results of using Ostrom’s SES Framework modified for assessing urban ecosystem services (Table 2). The subsystems characteristics are detailed, and the interactions and outcomes between each subsystem. In Figure 1, the geographical boundary of the city of Cádiz is defined according to the methodology of de Andrés et al. (2017, 2018). This analysis and information allow a context-based approach for the EMB-DPSER application.

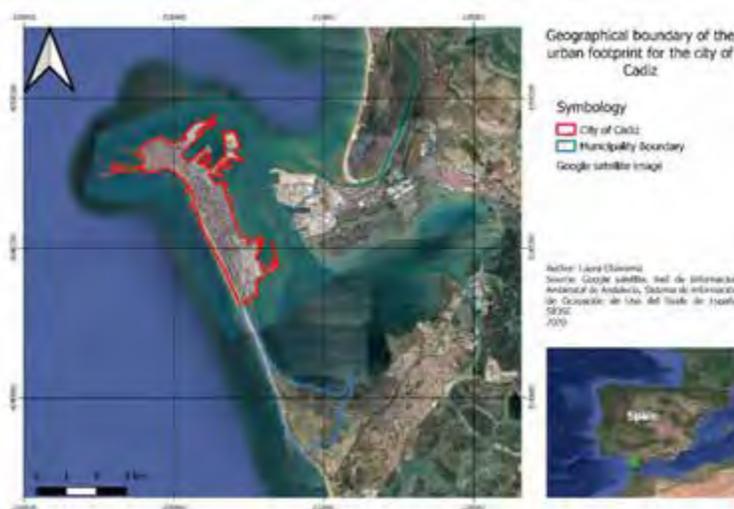


Figure 1. The geographical boundary of the urban footprint of the city of Cádiz

Table 2. Summary for SES Framework for this research

| SES Subsystems (variables) | Description (sub-variables) |
|----------------------------|--|
| Resource System | The city of Cádiz has an extension of 7.6 Km ² , with a population of 116 979 for 2016 (Figure 1). Therefore, the city has a density of 15 392 pp/km ² . It is a centre of services and economic activities; consequently, there is a lot of commuting from nearby communities. The city is completely urbanised, and it cannot expand further due to the marine areas. The main economic activities are “Sun and Beach” tourism and activities in the industrial port. |
| Resource Units | The main identified ecosystems are Parks, gardens and beaches. Using the Common International Classification of Ecosystem Services (CICES) from the European Environment Agency (2018), the ES provided by the urban ecosystem or the related ecosystem were mainly regulating and cultural services like recreation, ecotourism, cultural and aesthetic values, atmospheric regulation, water purification and treatment, water regulation, and others. |
| Related ecosystems | The city of Cádiz has three main ecosystems in its borders; on the first hand is the bay of Cádiz to the east, the open water of the Atlantic Ocean to the west, and the salt marshes to the south. The state of health of these ecosystems is critical to the well-being of the city’s population and economic development. In addition, many recreational, commercial, and cultural activities are related to ES provided by the sea and tidal marshes, mainly water purification, water regulation and recreation, which is extremely important for the tourist industry. |

| | |
|---|--|
| Governance system | According to de Andrés et al. (2020), there is a lack of political will to develop national policies to regulate the coastal zone. Every regional government can manage the coastal and urban areas as they please, responding to their constituents' economic and political pressures and not the Spanish ecosystems' global health. For the municipalities inside the Andalusia Region, the urban planning and the Integrated Coastal Zone Management are the regional government's responsibility ('Comunidad Autónoma de Andalucía') as is stated in their Statute of Autonomy [16]. |
| Social, economic, and political settings | The Spanish government has favoured economic growth for several years despite environmental damage or deterioration. However, the mobilisation of the economy from the agrarian sector to more service activities, tourism, and the construction sector has implied an overall dependence and inefficient exploitation of ES with a non-renewable nature. The Andalusian Autonomous Community has suffered this economic and social change, mainly due to its low economic development [17], [18]. |
| Users | The users include the current and future population, tourists, and workers that commute from other areas in the Bay of Cádiz and the industrial and economic activities developed in the city. The municipality of Cádiz has an aged population. Therefore, there is a tendency of low birth rates and low mortality, with a higher percentage of women than men [17]. |

Interactions

The Cádiz SES interactions between the users and the resource system and resource units have been extensive and intensive, provoking a deterioration and almost complete replacement of many ES at a high economic or social cost. For example, the reduced amount of UGA with the ageing population can directly affect the physical activity and cultural interaction that the population exerts, reducing their well-being significantly [19].

Another example is the high dependency on ES by tourism. People travel for the main reason to enjoy ES like recreational activities and leisure, enjoy a new landscape, or appreciate the social and cultural activities, making the city highly dependant on the ES given by UGA. Therefore, maintaining healthy ecosystems is imperative to continue tourist activity in the long term. Nonetheless, these principles are paramount by short term economic gain, provoking unsustainable practices like the sea's contamination, reducing urban green spaces, and atmospheric pollution due to the high atmospheric emissions.

Outcomes

After analysing the interactions and relationships between the SES, it is fair to determine that the City of Cádiz has exerted significant pressure on the city's ecosystems and those nearby.

The city does not have many UGA, limiting its capacity to provide ES. Only 7% of UGA corresponds to Parks, Gardens, beaches, and dunes. According to the recorded population in 2016, the city has only 4,55 m² per capita of UGA, half of the minimum recommended and a lot less than the desired 50 m² per capita to improve human well-being [20]. Nonetheless, the areas provide multiple cultural services, especially the beach and dunes, due to the recreational activities that increase the appeal of Cádiz as a holiday city for "beach and sun" tourism. In addition, the Cádiz Bay, the Atlantic Ocean and the salt marshes provide an important recreational and ecotourism space for the citizens.

Due to the small amount of UGA, there is not much space to support biodiversity or provide shelter for vulnerable species inside the city's limits reducing its genetic diversity, decreasing its capacity to control plagues or other diseases. This trend implies a reduction of ES for pollination and biodiversity. The small UGA limits climate regulation capacity. The UGA are primarily at the historical centre in the city's far northwest; therefore, carbon sequestration and local temperature control are very limited. The soil's permeability is minimal due to the extent of urban infrastructure, which increases runoff, urban flooding, and the aquifer's disequilibrium.

The beach supports fish stock and habitat for marine species and food supply, providing cultural ES in recreational fishing. The coast also permits nautical navigation, representing an industrial activity in Cádiz, and once more, provides recreation services in the form of nautical sports.

The city is also vulnerable to coastal flooding, and for this reason, the city has historical coastal defences to substitute the ES loss by the urbanisation process [21]

Other ES have human-made substitutes that come from other regions. For example, there is no recording of urban agriculture in Cádiz at present. Therefore, besides some fish caught in the bay, all the food in the city is imported from other regions. The drinkable water supply comes from la Sierra de Cádiz, so there is no fresh water supply in the city or wells for drinkable water consumption [22]

For sewage assimilation, the city of Cádiz uses a wastewater plant located in San Fernando, outside the city limits nonetheless some industrial wastewater disposal from the port has been registered [23]. For waste disposal, the city depends on facilities in the municipality of Chiclana de la Frontera (Ayuntamiento de Cádiz, 2010, 2012)

EBM-DPSER ANALYSIS OF THE URBAN AREAS.

Drivers and pressures

The main drivers, pressures, state and relationship with the ES are displayed in Table 3, which were established using the gathered information and analysis of the cities with the SES Framework.

Determination of the state of the affected ecosystem and its Ecosystem services

Table 3. Pressures, State, ES, and remote sensing techniques to measure the state.

| Drivers | Pressures | State | ES (CICES) | ES (MA) | Remote sensing |
|---|--|-------------------|--|--------------------------------|---|
| High interurban mobility from other cities in the area. | Increase in atmospheric emissions | Atmospheric state | Atmospheric composition and conditions | Atmospheric regulation | Atmospheric emissions (NO ₂ emissions) |
| Lack of urban space | Increase urbanisation for touristic accommodations and population housing | UGA cover | Spiritual, symbolic, and other interactions with the natural environment | Spiritual and religious values | NDVI |
| Sun and Beach tourism | Increase residents and tourists, increase wastewater production, increase maritime traffic, increase the beach and recreational sea use. | Water quality | Physical and experiential interactions with the natural environment | Recreation and ecotourism | Chlorophyll Total Suspended Matter |

Atmospheric State

The spatial distribution of [NO₂] in the atmosphere for April 2019/2020, and August 2019/2020 is shown in Figure 1. The atmospheric column showed a lower [NO₂] during April 2020 (Fig. X.B) compared with April 2019 (Fig. X.A). This is highly correlated to the COVID 19 pandemic mobility restrictions, which dramatically reduced traffic and transportation. Once these restrictions were removed the [NO₂] in the atmosphere increased. This is clearly seen in the comparison between August 2019 (Fig. X.C) and 2020 (Fig. X.D). The mobility restrictions gave a great opportunity to analyse their effect on [NO₂] and hence to the air quality associated to human activities.

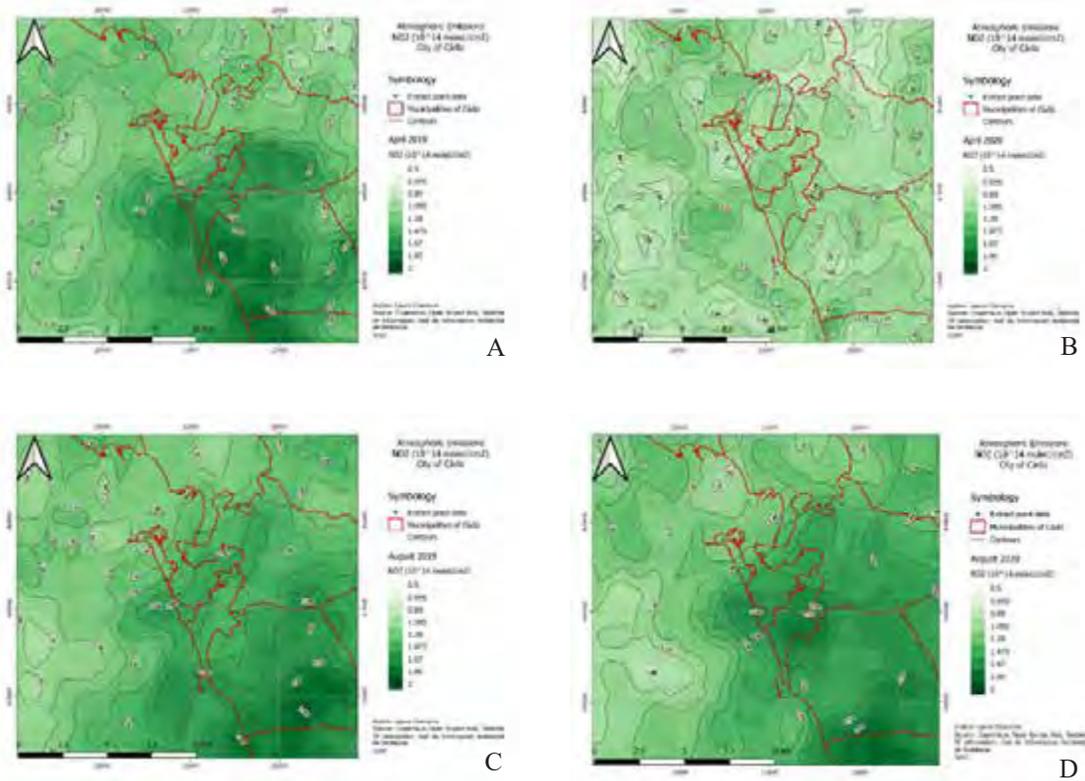


Figure 2. Tropospheric NO₂ column density in Cádiz for April 2019 (A), April 2020 (B), August 2019 (C) and August 2020 (D)

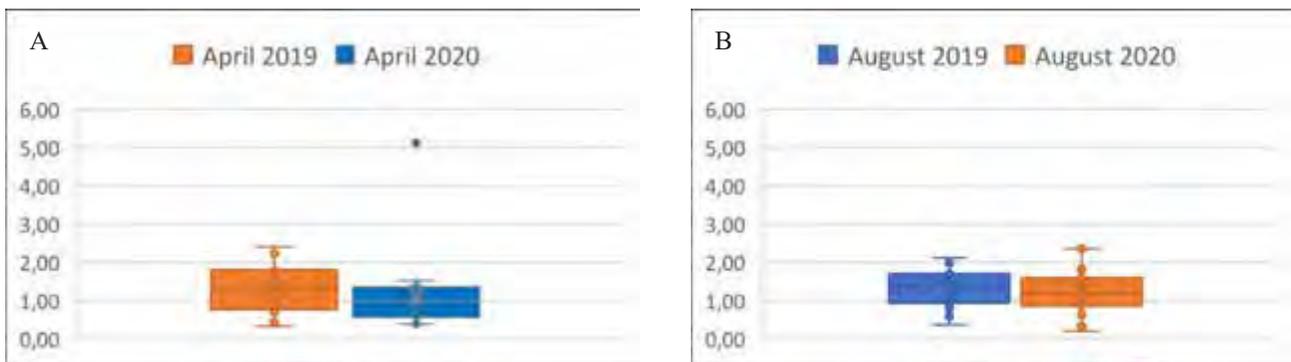


Figure 3. NO₂ ($\times 10^{14}$ molec/cm²) for April 2019 and April 2020 in Cádiz (A) and for August 2019 and August 2020 (B)

Urban green areas cover.

The results show vegetated city areas when the index is higher than 0.199 (Figure 4). Using Landsat images from 2013 and 2020, this research compares vegetation states in the selected cities.

Utilising the NDVI data and GIS tools, it was determined that Cádiz has maintained the same cover in 81% of its total area in 2020 than 2013, has a slight vegetation improvement on 16% of its territory and a slight deterioration on the vegetation cover on 4% of its area.

The NDVI allows monitoring isolated vegetation like street trees, private gardens, empty land, or green infrastructures like vertical gardens or green rooftops. Therefore, it does not coincide with the Corine Land Cover, but furthermore, it allows to measure the urban vegetation more accurately.

The results also corroborated the preference with the Sentinel 2 imagery against the Landsat 8 imagery. The Sentinel 2 imagery's high resolution permits further detail and fewer errors in interpreting the pixel information. This data characteristic explains why the Landsat 8 NDVI from 2020 (resolution 30m) is different from the Sentinel 2 NDVI from 2021 (resolution 10m). A correlation test was performed for the raster with a final correlation of 0.95, demonstrating the similarity between the data.

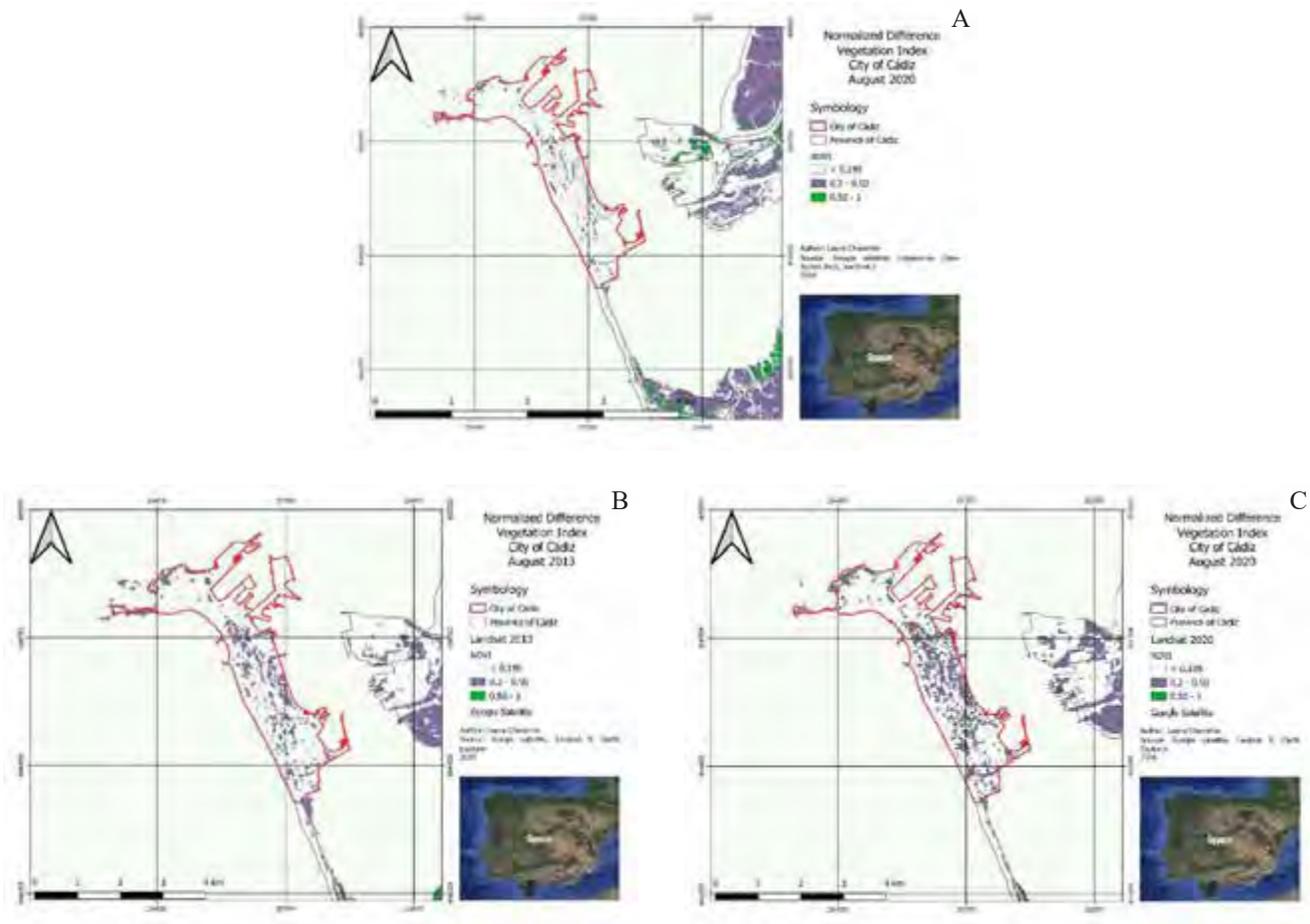


Figure 4. NDVI for City of Cádiz with Sentinel 2020 (A), Landsat 2013 (B) and Landsat 2020 (C)

Water quality

The following results show a higher chlorophyll and total suspended matter inside related ecosystems (Figure 5). The higher results in these parameters can be due to the natural regime; however, it is most likely influenced by anthropogenic pressures on urban areas and wastewater disposal.

These two parameters are indicators of pollution attributed to the human impact produced in urban areas and industrial complexes. The nutrient concentration increases in areas exposed to agriculture runoff, sewage disposal, and vehicular and industrial emissions. Chlorophyll concentrations increase due to algae blooms favoured by nutrient-rich environments, especially nitrogen and phosphorus. The suspended matter is correlated to sediment transportation, erosion and disposal of organic matter (Ritchie et al., 2003; Siswanto et al., 2011).

As detailed in the figures, the amount of chlorophyll and total suspended matter increases in the river and river mouth for Sanlúcar de Barrameda and Conil de la Frontera, probably related to urbanisation of wastewater and the influence of the river sediment discharge. The river also carries the runoff and sediment movement from the agriculture fields, linked with sediment and nutrient increase. In Algeciras and Cádiz, the chlorophyll and total suspended matter increase in the bay where the ports are located, implying an environmental impact due to maritime traffic and port activities. The area between Conil de la Frontera and Algeciras has a lower urban development. Consequently, it presents lower chlorophyll and total suspended matter, suggesting an anthropogenic influence on the water quality in regions with higher urbanisation. Further hydrological and environmental studies should be performed to identify contamination sources on the selected cities' related aquatic ecosystems.

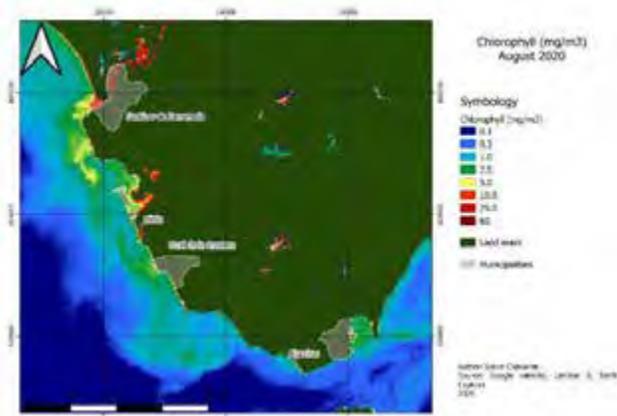


Figure 5. Chlorophyll-a (mg/m3) in August 2020 (mg/m3)

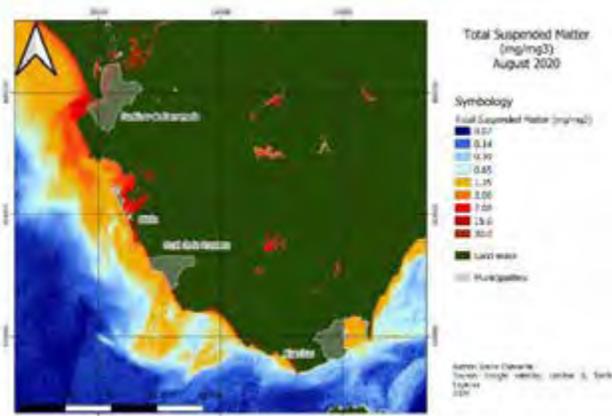


Figure 6. Total Suspended Matter (g/m3) in August 2020

Responses

Once the ecosystems and their services were analysed with remote sensing techniques, responses were constructed to ensure human well-being based on the information according to the SES framework (Table 4).

Table 4. Responses to improve the state of the ES in the cities.

| State | ES (MA) | Response |
|-------------------|--------------------------------|--|
| Atmospheric state | Atmospheric regulation | <ol style="list-style-type: none"> 1. Monitor atmospheric emissions by correlating with ground-based information. 2. Increase the amount of urban vegetation to improve atmospheric regulation. 3. Encourage public transportation and alternative transport like bikes and skates to reduce private vehicles. 4. Control and monitor gentrification in the city of Cádiz. |
| UGA cover | Spiritual and religious values | <ol style="list-style-type: none"> 1. Increase the UGA inside the city boundaries. 2. Promote new nature-based solutions and green architecture (Green rooftops, green walls) and increase street reforestation. 3. Promote urban and household agriculture. |
| Water quality | Recreation and ecotourism | <ol style="list-style-type: none"> 1. Monitor wastewater disposal, runoff water quality, and waste disposal from ships. 2. Increase wastewater quality parameters for wastewater disposal inside the bay. 3. Monitor port activities that can provoke an increase in organic matter. |

DISCUSSION

This research works under the awareness that cities are social-ecological systems with complex relationships between their components and the reciprocity between ecosystems and humans. It also acknowledges the complexity of studying cities as a unique system, although it recognises the importance of understanding the environmental and social needs of one interrelated system composed of many variables [31], [32].

Under this premise, it was possible to delimit the study areas as a defined social-ecological system by using the geographical boundaries of shoreland proposed by de Andrés et al. (2017). This process resulted in several outputs necessary for the spatial analysis of the cities as a social-ecological ecosystem. First, delimiting the areas allowed the analysis of the urban ecosystems inside the city boundaries, separated from related ecosystems that greatly influence the area but are not part of the urban centre, to detect possible urban sprawling and monitor the loss of these related ecosystems.

These results were consistent with the information reported by de Andrés et al. (2017) and de Andrés & Barragán (2017), which describes the Spanish coast's social-ecological system. In their research, the province of Cádiz and, specifically, the municipality of Cádiz is part of the coastal uplands. Therefore, at a closer look, the municipality's urban areas are classified as shoreland, like it was described for Cádiz by de Andrés et al. (2018).

Cádiz has almost the same social-ecological geographical boundaries as its administrative border. This reality is not attributed to proper urban planning but the geomorphological conformation. Cádiz is a peninsula, which means its area is limited by seawater, allowing only a specific amount of urban growth, which the city has already reached, making urban growth almost impossible. However, the port seems to continue its expansion, taking area from the bay's natural ecosystem.

The SES Framework helped identify the ecosystem and its services and described the citizens' connections with them, the threats and pressures to human well-being, and the main reason the threats and pressures exist. Thus, the framework allows for a better understanding of the city's needs. It can help develop a more holistic urban plan that uses nature-based solutions and improved ecosystem services for a more sustainable and resilient city. The employment of the SES framework for analysing complex systems has been underway in the last 20 years with multiple examples and case studies due to its methodological flexibility [1], [7], [34]. Nonetheless, the SES framework for urban system analyses must be further developed to gain accessibility to the urban managers, especially if combined with other environmental frameworks like ecosystem services or the DPSIR [35].

The ecosystems and the ES were detected using the urban land cover and analysed using the CICES list of ES. The ecosystems detected have been very similar to other studied urban ecosystems. However, the added particularity that the selected cities are located in the coastal zone adds their own set of ecosystems and services [1].

This research concluded that Cádiz is highly dependent on the ecosystems and their ES. For example, it has a significant economic and cultural dependency on water and coastal ecosystems. Also, as in many cities worldwide, both inland and sea, fossil fuels for private and public transportation have negatively affected air quality [36]. This environmental impact can have a direct effect on human health and well-being. Therefore, the presence and development of urban green areas are essential urban ecosystems due to the myriad of ES that it provides to its population, including air quality control [20].

Like any other city, Cádiz requires an external supply of provisioning services like food, timber and freshwater [5]. In addition, urban green areas provide regulating services, although unfortunately, the extension of urban vegetation is limited. Concerning cultural services, the urban green areas and coastal zone are essential ecosystems that directly influence human well-being, making their enjoyment a priority for improving the quality of life inside the city boundaries [19].

With the EBM-DPSER framework, this research identified each of Cádiz's primary drivers and pressures associated with their economic and social activities [12], [35]. For example, according to the SES framework results, Cádiz is a historic port city with few natural ecosystems inside the city's boundaries but a tight relationship with the related ecosystems. This study also concluded that the area is highly urban due to historical development in the city. It does not possess opportunities to traditionally increase the amount of urban vegetation in parks or gardens. It has a high dependency on the coast, ocean, and bay, but also it exerts tremendous pressure due to wastewater disposal and port activities. The methodology also permitted determining that the city is suffering gentrification, enhancing workers' need to commute from outside the city and increasing atmospheric emissions.

Other applications of DPSIR or its variants have found similar drivers of pressures in the Bay of Cádiz. For example, both Barragán Muñoz & Andrés García (2020) and Camilleri (2015) mention tourism as one of the main drivers in the Bay of Cádiz. Camilleri (2015) also mentions transport and communications, infrastructure for public use, and wastewater disposal, similar to this research findings. Additionally, both applications of the DPSIR in the Bay of Cádiz mention that governance and public policies are among the main drivers for the region, highlighting the importance of urban and environmental management in this area.

The atmospheric emissions are caused mainly by private vehicles commuting to other cities for work, exacerbated by the inefficient public transportation network. Finally, the tourist industry is highly dependent on the ES supplied by the water bodies, mainly recreational services; nonetheless, the coast has experienced a deterioration due to wastewater disposal and runoff.

The city's problems are not isolated issues; they are well-known phenomena that have caused environmental deterioration and reduced human well-being in many cities and regions worldwide [39].

It was possible to measure a state change in the ES with remote sensing techniques [14], [40]. These measurements define if an ecosystem like green areas reduces its cover inside the city's boundaries or if the air or water quality has deteriorated due to human impact. These relationships will allow an urban manager to create, adapt and monitor environmental measurements to improve human well-being.

This method of analysing SES aims to avoid recommendations that do not fit the reality of complex systems provoking the loss of resources and decreasing the possibility to create sustainability in the city [32]. Thanks to the SES framework, this research developed responses and actions adapted to the city's needs to improve the ES's state and, therefore, human well-being. The SES has proven to be an invaluable tool for understanding the reality of the systems and their interactions and developing sustainable, holistic, and inclusive responses. Many of the responses given are standard environmental practices based on EBM, but unfortunately, the results show the need to implement or improve them. Some of these practices are the regulation and improvement of wastewater treatment plants, the increase of urban green areas, the promotion of green infrastructures like green roofs or green walls.

CONCLUSIONS

This research proposed that Ecosystem-based management responses suitable for the city's needs using the information from the SES Framework and the data on the change of state provided by the remote sensing techniques, demonstrating the importance of understanding the urban areas' needs before implementing any measurement or responses.

Overall, this research adheres to the Ecosystem-Based management principles by enhancing ecosystems' functions and integrity for human benefit, recognising ecosystems' boundaries, and encouraging biodiversity. This research also provided tools to measure change and recognise the citizens as the ecosystem users and services, including multi-sector analysis. Finally, this methodology is accessible for any urban manager, thanks to its low cost and efficiency, and promotes EBM principles in several aspects of the urban management process.

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A GAME-LIKE APPROACH FOR CAPACITY BUILDING AND AWARENESS RAISING IN CLIMATE CHANGE ADAPTATION

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ABSTRACT

Adopting game-like approaches in capacity building activities allows obtaining effective results, in particular when dealing with complex issues such as climate change. A clear understanding of basic concepts might be indispensable to work with increasing complexity. For example, heat wave mortality estimates vary depending on the definition given to this hazard, whereas adaptation to climate change depends inexorably on how vulnerability is defined. We present here an exploratory tool to enhance the communication of climate change related concepts tested and implemented in the occasion of several workshops in different regions of the world in the framework of the Global Covenant of Mayors (GCoM) initiative. The game-like approach consists of a photographs-selection where participants –with diverse profiles– are divided in groups and have to correctly identify the components of risk and recognize the relation between climate risks and corresponding adaptation actions. The aim of the activity is to reinforce basic knowledge to help climate practitioners in further developing their climate related work by visualizing the concepts and figure out the steps to be undertaken. The exercise was reported to be successful by participants, thereby, showing its potential in strengthening the basic knowledge on adaptation to climate change and its replicability in other cases and contexts. It highlighted that the assimilation of the concepts varies depending on the climate risk analyzed. Through this activity, a structured approach for climate change adaptation rooted in prevention, forecasting and monitoring systems instead of emergency is given.

KEYWORDS

capacity building, climate change adaptation, Global Covenant of Mayors, exploratory game-like tool

INTRODUCTION

Having a clear understanding of basic underlying concepts, such as hazard, vulnerability, exposure, risk, and impact is indispensable to achieve effective results when dealing with complex issues such as climate change adaptation. For example, heat wave induced mortality estimates vary depending on the definition given to this hazard [1]. While climate adaptation can be achieved by reducing vulnerability, this becomes dependant on how vulnerability is defined [2]. Similarly, Allen et al. [3] highlighted that there is a deficient precision on how climate risk is defined, misguiding the scientific community when climate change impacts have to be assessed and climate adaptation actions proposed.

Madsen et al. [4] noted that the most common terms of climate change adaptation remain rambling for stakeholders concluding that differences in definitions could lead to contentions, undermining the advance in adaptation as well as the city's capacity for change. These authors propose that further work should concentrate on developing and communicating a clear and inclusive definition of climate change adaptation. Moreover, knowledge exchanges are crucial for decision-making, in particular when addressing climate change adaptation for which the development of collective learning is essential. Researchers are exploring numerous and different approaches for climate-related knowledge co-production [5]. For instance, numerous studies confirm that adopting game-like approaches allows boosting transversal skills, increasing knowledge and data collection on a specific topic, and supports decision-making [6]. According to the existing literature, games related to environmental governance boost eagerness to participate by giving a voice to people that are not often engaged [7]. Such approaches also inspire thinking about specific planning decisions [8,9], leading to more reliable and rigorous interaction between researchers, decision-makers and stakeholders [10] and have been used in numerous research fields. Furthermore, games provide a win-win solution since they bring together motivation and pleasure in the process of interaction between citizens and planning experts [11,12,13]. These approaches are also useful as icebreakers during participatory workshops [7].

This paper describes a game-like approach applied in training activities for enhancing the communication and understanding of climate change adaptation concepts by using printed images. This exploratory tool has been used during several workshops in different regions of the world in the framework of the Global Covenant of Mayors for Climate and Energy (GCoM) initiative.

LITERATURE REVIEW

Active creation of knowledge to engage in the climate change debate is necessary, requiring innovative paradigms [14]. In capacity building activities there is the need to outpace the traditional one-direction instructive approach and become facilitators during learning processes [14], in order to reshape the way climate change is addressed and communicated [15]. Capacity building workshops are powerful tanks for science for policy initiatives, science exchanges and learning approach testing. Workshops are occasions to shed light on existing scientific knowledge, as well as on how solving central scientific problems [16]. Capacity building workshops help to interchange evidence among academics, policy officials and decision-makers [17,18]. Participatory workshops are appropriate to talk about necessary actions to tame environmental problems, as climate change [19], inspiring participants to remain working organically [16]. These activities are also called community-based workshops, which have been adopted to construct adaptive capacity and initiate climate change adaptation strategies. Thus, community-based methodologies allow expanding the knowledge of present and future climate [20] while reflecting on the causes of vulnerability, e.g., detailed work on flood risks analysed by [21] addressing the causes of vulnerability to floods.

Various techniques have been adopted during capacity building workshops on climate change adaptation. For instance, the work carried out by [22] used: (1) values and narratives to plot scenarios that might be useful to detect climate actions, (2) pre-arranged narratives with the intention of classifying positive and negative keywords and judgements; and (3) design new narratives to enhance consensus and improved climate communication. [9] offered diverse valuable tools for workshop meetings, such as the group model building, the adaptation support tool, and the stress test guideline, as well as a dialogue-based tool-free approach. Group model building is an analytical method for organising and exploring systems in small groups (e.g. [23] on participatory modelling and [24] for water resources management). The adaptation support tool is a touch-table-based platform where participants can explore adaptation by means of the assortment of geo-referenced adaptation actions (e.g. [25] for urban adaptation). The stress test guideline is a stepwise system adapted to evaluate urban resilience through the collection of vulnerabilities and possible solutions (e.g. [21] who showed presentations on flood risk zones, round tables to detect solutions, and negotiations to prioritise measures, and [20] who gave presentations to elucidate climate action, organised focus groups to

ascertain climate risks and shepherd individual work to prioritise actions). Lastly, the tool-free approach consists of sitting together with experts to agree on how to manage adaptation planning and to plan solutions. This last technique has been applied to boost the involvement of IPCC practitioners [17].

Other lines of thought have applied visuals to enhance learning and co-create knowledge during capacity building workshops. It is known that people tend to understand better their surrounding environment through images [26]. Furthermore, visualization tools are known to support the teaching of climate change dynamics [27,28], since visualisation is easier to understand than raw data or algorithms [29,30]. Visual images have the ability to call people's attention toward concrete messages [29] as well as to motivate climate action [27]. Visualisation comprises a new approach to involve decision-makers and the community on analysis of climate change scenarios [31]. However, the challenge is how to use visuals imaginatively to tackle effective climate change communication [29].

A sporadically used method among social scientists and planners to procure knowledge is the Photo-elicitation [26]. For example, photography enhanced the involvement of women in water management, by taking pictures of local scenes to reveal the effects of climate change, as well as to argue and share the information with government officials [32,33]. The use of photos is also suitable to have a richer impression of flood risks [34]. However, it is also known that photographs cannot capture the whole complexity, invisibility and changes of a certain system [29]. A different form of visualisation is, for example, the "safety walks" [35], which is an exercise where citizens, climate change officials and stakeholders walk together to identify climate risks at municipality level. Another example can be found in [34] who applied the "safety walks" to flood-prone zones with citizens and flood risk authority representatives to enhance discussion on potential impacts and actions.

MATERIAL AND METHODS

Global Covenant of Mayors framework

The Covenant of Mayors (CoM) "2020 target" initiative was launched in 2008 by the European Commission to support the efforts deployed by local authorities in the implementation of sustainable energy policies. Local authorities voluntarily committed to reducing the total emissions by at least 20% by 2020, through the implementation of a Sustainable Energy Action Plan (SEAP). In parallel, in 2014, in the context of the European Strategy on adaptation to Climate Change, the European Commission launched a separate initiative called Mayors Adapt, based on the same principles as the CoM. Mayors Adapt focused on adaptation to climate change and on the support to local authorities in the development and implementation of local adaptation strategies (Bertoldi et al., 2018). In 2015, the CoM and Mayors Adapt initiatives merged into the Covenant of Mayors for Climate and Energy that adopted a threefold vision: reduction of greenhouse gas emissions, strengthen the capacity to adapt to unavoidable climate change impacts, and ensure universal access to secure, sustainable and affordable energy services for all. The key document of the initiative is the Sustainable Energy and Climate Action Plan (SECAP) that is a politically adopted document including the current condition of the signatory in terms of emissions, a climate risk assessment, and actions to be implemented to achieve the mitigation and adaptation targets.

In 2017, the Global Covenant of Mayors for climate and energy (GCoM) was launched, bringing under a harmonized approach the commitments of local governments worldwide. A set of new common recommendations (Common Reporting Framework - CRF) allows signatories to operate under the shared vision of the GCoM with principles and methods that best suit their region [36]. The CRF covers the key elements of GCoM (emissions inventories, targets, climate risk assessments and climate action plans) and allows consistency with national and/or sub-national requirements for local governments within their own context. The implementation of the GCoM in the different regions of the world has been supported through the International Urban Cooperation (IUC). The Joint Research Centre (JRC) provides scientific and technical support to the initiative, ensuring the methodological adaptation to the different regions of the world, providing guidance material, evaluating the plans, providing feedbacks to signatories, and preparing and giving trainings and workshops to experts and city representatives on SECAPs and on the Covenant pillars.

The activity described in the next paragraph has been developed by the authors in the framework of GCoM trainings to strengthen climate change adaptation framework and related key concepts involving the stakeholders that are actively addressing climate adaptation. The training activities implemented interactive methods through a game-like approach involving numerous participants.

A game-based learning approach to assimilate adaptation-related concepts

We present an exploratory tool to identify, assimilate and communicate the key concepts of climate change adaptation (in line with the climate risk framework of IPCC, AR5): hazard, exposure, vulnerability, risk, impact, and adaptation (see definitions in Table I).^a The tool has been tested and implemented in the occasion of several workshops in different regions of the world in the framework of GCoM. The activities developed by the authors during these capacity-building activities rely on the visualization potential of images to enhance the comprehension of climate change adaptation.

The game-like approach presented in this study consists of a selection of photographs where participants have to identify the concepts of hazard, exposure, vulnerability, impact and related adaptation actions, by assigning a representative image. The aim of the activity is to help climate practitioners to clarify these concepts with the support of visualisation and contextualisation. This activity has been dedicated to climate change officials, experts, civil servants, and other stakeholders and citizens interested in climate change, including non-climate experts as further explained in the following sections. Initially, participants –with diverse profiles– are divided in groups of five to ten people. Each group is given the same lot of 100 photographs (see Fig. 1) with diverse subjects and topics, with only some of them related to climate change (mitigation and adaptation).

Table I: Key concepts of the adaptation framework

| | |
|-----------------------|--|
| Hazard: | The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources» ([37], p. 124). |
| Exposure: | «The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected» ([37], p. 123). |
| Vulnerability: | «The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt» ([37], p. 128). |
| Risk: | «The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur» ([37], p. 127). |
| Impact: | «Effects on natural and human systems. In this report, the term impact is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system» ([37], p. 124). |
| Adaptation: | «The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects» ([37], p. 118). |

Fig. 1 shows the material preparation by the moderators (and authors of this study).



Figure 1. Preparation of the photos for the activity by the moderators

A climate risk is assigned to each group (see Table 3 for examples), that has to identify a single picture for each concept of the climate risk framework [37] described in a previous section of the workshop^b consistent with the risk assigned. The risks were adapted to the local climate characteristics of the region where the training took place (following the IPCC Part B - regional aspects reports^c) in order to guarantee the maximum level of engagement. As mentioned, before starting the interactive activity, the moderators presented the key concepts (Table I), in order to ensure that all the participants have a common based knowledge of the topic.

All groups had 45 minutes to implement the task, and after completing the first activity, each group had another 15 minutes to explain their results as well as assess the activity. At the end of the exercise, the moderators provided the groups with some pre-evaluated solutions against which compare the groups' results. The presentation of the results of each group was recorded, as well as the feedbacks given to the authors of this paper. Lastly, the moderators circulated an anonymous online questionnaire to know the opinion of the participants concerning the game and its effectivity to assimilate the concepts. The method did not go through a pre-testing phase. On the contrary, it was directly applied in real contexts with concrete examples. The photographs were searched on the web by introducing keywords in a search engine. Key photographs were chosen per type of risk. Then, another lot of photographs not related to the subject were also selected in order to mislead the participants and make the game more challenging.

Case studies

This method was applied in capacity building workshops developed in different regions of the GCoM initiative: South East Asia - Johor Bahru (Malaysia), Latin America - Corrientes (Argentina), North America - Guadalajara (Mexico) and Europe - Palermo (Italy). In the following sections, the four trainings are introduced and outcomes discussed and compared. Table II shows a summary of the methods applied to diverse case studies and Table III shows the risks adopted in the different regions according to their local specificities. Each risk was assigned to a different group.

Table II. Methods applied to the case studies

| | A) Johor Bahru (Malaysia) | B) Corrientes (Argentina) | C) Guadalajara (Mexico) | D) Palermo (Italy) |
|------------------|---------------------------|---------------------------|-------------------------|--------------------|
| Activity | ✓ | ✓ | ✓ | ✓ |
| Audio recordings | ✓ | ✓ | ✗ | ✓ |
| Questionnaire | ✓ | ✓ | ✓ | ✗ |

the tick indicates that the method was applied

Table III. Climate risks used in the case studies

| A) Johor Bahru | B) Corrientes | C) Guadalajara | D) Palermo |
|----------------------------|------------------------------|----------------------------|------------------------------|
| Heat stroke | Heat stroke | Heat stroke | Heat stroke |
| Water scarcity | Water scarcity | Water scarcity | Water scarcity |
| Losses due to river floods | Losses due to river floods | Losses due to river floods | Losses due to river floods |
| Ocean acidification | --- | --- | --- |
| --- | Losses due to coastal floods | --- | Losses due to coastal floods |
| --- | Casualties due to cold waves | --- | --- |
| | --- | Wildfires | Wildfires |

The first activity took place in Johor Bahru (Malaysia) in March 2019. The activity was part of a three-day workshop focused on adaptation. 35 people attended the workshop and were divided in four groups of seven to ten people. The groups were heterogeneous, avoiding similar profiles in the same group.

The second activity took place in Corrientes (Argentina) in August 2019. The activity was part of a workshop based on the three pillars of climate action: mitigation, adaptation and access to energy. 40 people attended the workshop and were divided in five groups of eight to ten participants.^d

In September 2019 a two-day workshop on mitigation and adaptation was held in the region of Guadalajara in Mexico. The activity took place during one day dedicated to adaptation. After describing the IPCC framework and the key concepts of climate risks, the practitioners were gathered around in four groups of six to seven people.

The last workshop was held in December 2019 in Palermo (Italy). Participants were municipal representatives and external experts involved in the preparation of SECAPs. All participants came from the Italian region of Sicily. It was a two-day training focused on adaptation only. Seven groups of four/five people were organised.

The same team of facilitators have led the activity in the four different workshops.

RESULTS

The results can be presented from diverse perspectives. One perspective focuses on how many *matches* (pre-evaluated solutions vs photographs proposed by the groups^c) were found for the adaptation-related concepts per case study (see Fig. 2). Thus, the larger the score (%), the more matches occurred between the proposal given by the moderators and the proposal given by the participants. Fig. 3 shows an example of the activities in the four case studies. Therefore, in this study the percentage of matching is considered as an indicator of the level of understanding of the key concepts related to a specific risk.

Fig. 2 shows that, in general, the participants of case studies A and B (Johor Bahru and Corrientes) presented a higher percentage of matches than those of cases C and D (Guadalajara and Palermo) (the following section reports further insights). Even though A and B's outcomes were similar, the participants of Johor Bahru presented more matching results for the concepts "hazard", "exposure", and "vulnerability", whereas the participants of Corrientes performed better for the concepts of "impact" and "adaptation". In the cases of Guadalajara and Palermo, the participants of Guadalajara presented more matches for the concepts of "hazard" and "exposure", whereas in Palermo the concepts of "vulnerability", "impact", and "adaptation" were better perceived.

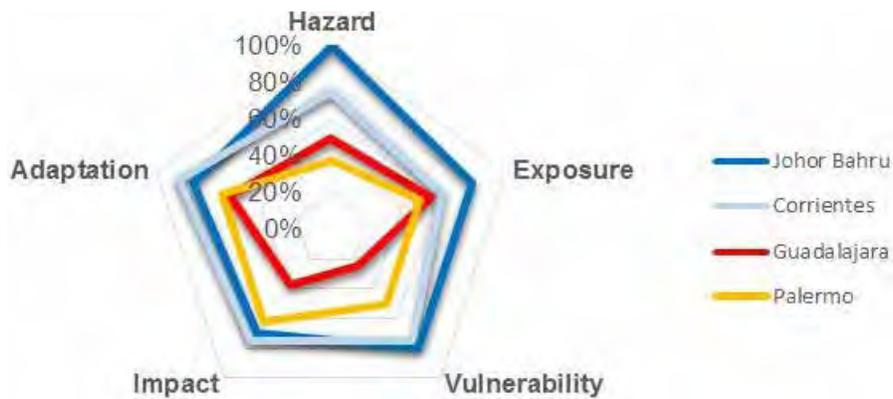


Figure 2: Percentage matches per type of concept and case study

Another perspective from which the results can be shown is the score obtained by type of risk. According to Fig. 4, the number of matches differs depending on the risk analyzed. For example, for all case studies, the risk for which groups showed higher matching was "losses due to coastal floods" (only explored in cases B and D). The two case studies presented almost a full match (as previously mentioned, all case studies had the same lot of photographs). Also, ocean acidification presented a high rate of matches; however, this risk was only analyzed in Johor Bahru (see some examples of the results in Fig. 5). Finally, water scarcity, common in the four case studies, had on average a fairly high score suggesting a common good understanding of this specific risk.

Conversely, the four case studies showed that the risks of "heat stroke" and "wildfires" were more complex for participants to be correctly assessed. With respect to the former risk, the group of case study B (Corrientes) performed the activity 100% correctly. In the case study A (Johor Bahru), the group in charge of "heat stroke" selected 11 pictures although the activity's rule allowed the selection of five (one per each dimension). The same case was identified in the group in case study C (Guadalajara) that selected 12 photos. In particular, these groups had difficulties to distinguish "exposure" from "vulnerability", as well as "impact" from "adaptation".



Figure 3. Photographs of the exercise



Figure 4: Percentage of correct answers per type of risk: all case studies

There is a number of uncertainty components at the basis of the method that may influence these results, and, hence, imply that the use of the matching as an indicator of understanding may leave some level of fuzziness. One of these components is the group composition, which may influence the results, as the presence of experts on a topic or participants having never dealt with the specific risk assigned, can produce a different result. The same group could have reached different results if assigned a different risk. Another aspect to be further investigated when replicating this activity, would be to understand if the activities' outcomes are related to the risk assigned to each group, thereby having a better performance with a different assignment.

The case of Palermo shows, however, that the result of the exercise is not strictly linked to the type of risk. The risks of “water scarcity” and “losses due to coastal flood” were replicated among different groups because of its importance for the region. In these cases, the groups working on these risks gave different results. In particular, in both risks one group presented a full match with the pre-evaluated solutions while the other group showed confusion between “exposure” and “impact”. As shown in Fig 5, many groups decided to use more than one photo for each component. This might be a consequence of the difficulty to make a single choice since numerous assets and people are at stake and multiple perspectives, coming from personal experience and site-specific knowledge, are available when dealing with climate change adaptation.

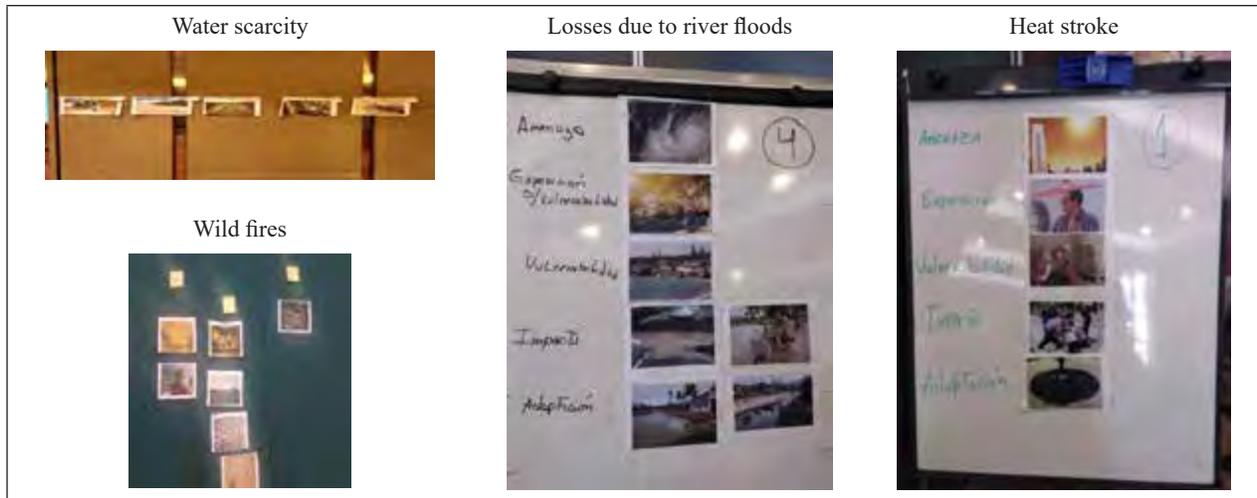


Figure 5: Some examples of the results obtained

The participants gave their feedback to the authors on how they evaluated the activity (i.e., whether they felt it useful or not to assimilate the climate adaptation concepts) through an on-site assessment and an on-line questionnaire.

With regards to the results obtained in the on-line questionnaire, the participants of case study A (Johor Bahru) (as seen in Fig. 6) agreed 100% with the fact that the activity was useful for assimilating adaptation-related concepts (29% strongly agree with the statement, whereas 71% agree with it). On the other hand, 90% of the Corrientes' participants agreed with the usefulness of the photo-activity as well (42% strongly agree and 47% agree). In Guadalajara, the percentage reached 92% (77% strongly agree and 15% agree), indicating that almost all participants found the activity extremely useful and more effective than a presentation. Concerning the time allocated to carry out the game, there are however interesting differences among the case studies (see Fig. 7). For example, 31% of respondents in Corrientes considered that the exercise was too long. Conversely, 69% and 61% of the participants respectively in Johor Bahru and Guadalajara think the exercise was too short, which, as mentioned, could be linked to the expertise of the group and the risk assigned.

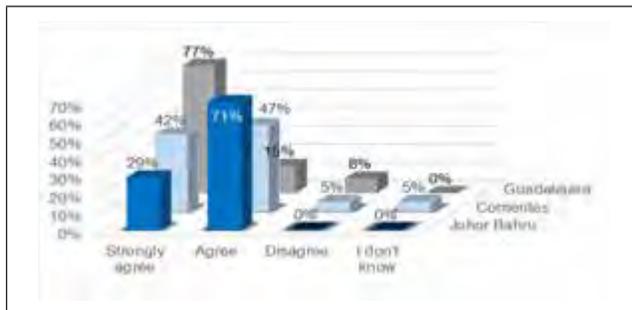


Figure 6: Results provided by the participants to the question: "has the game been useful for assimilating concepts?"

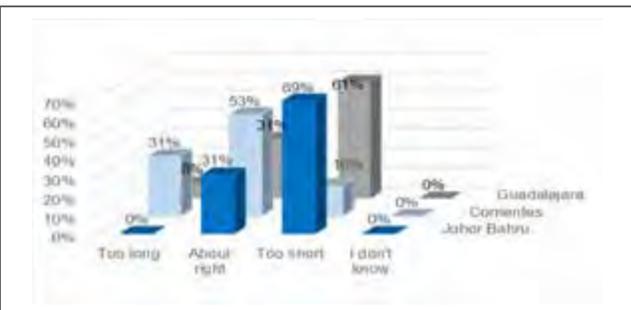


Figure 7: Results provided by the participants to the question: "has the game had enough allocated time?"

DISCUSSION (OUTCOMES FROM THE PARTICIPANTS EVALUATION)

The potentials of the exercise have been highlighted by the four case studies. A marked majority of respondents considered that the exercise was either useful or very useful to assimilate the concepts related to climate change adaptation, even though the exercise was found challenging due to the large number of photos. These views provided through the questionnaires were complemented by the on-site assessment of the participants. Consequently, the photo activity might be seen as an exercise to enhance adaptive capacity and anticipatory learning, as highlighted by [10]. One of the most repeated comments referred to how practical the photo-game was. For example, one participant in Corrientes stated that: "it was very practical, very

concrete”, while in Johor Bahru a participant indicated that the “*exercise is very good. The pictures are very good to describe things*”. Other comments obtained in Corrientes mentioned its learning capacities: “*it is an exercise that allows us to reflect and incorporate learning in relation to what a hazard, exposure, vulnerability, etc. means*”. “*For me it was a very enlightening screenshot of all the concepts to deal with*”. This statement is consistent with the results obtained by [10].

In Guadalajara, a participant declared that “*this activity was key to really understand the basic concepts shown in the preliminary presentations. The game helps in identifying the different components needed to analyse when developing and implementing measures to mitigate and adapt to climate change*”.

It has also been stated that the activity is an engaging exercise for the participants. As said in Johor Bahru, the photo-game “*is a good method, is a good approach to make everybody participate in this discussion*”. This statement coincides with the work developed by [8], who found game-based approaches as an interactive engagement activity among stakeholders towards decision-making. And also “*this is a good discussion because we have time to understand better*”. Other participant in Johor Bahru mentioned that the difficulty of assimilating the concepts is solved through the game-exercise: “*it is hard to understand [the concepts] but by looking at the pictures it turns out easy*”.

The use of photos that highlights the impacts of climate change on human beings and welfare seemed to be useful for the participants to understand the concepts of adaptation. As said in Corrientes: “*what we liked the most is the humanity they [the authors] put into it*”. Similar comments were also found in Johor Bahru, e.g.: “*I really appreciate how you attract people to participate more in this exercise.*”

Participants from Guadalajara mentioned the fact that they are already working on adaptation, implementing adaptation actions because of emergency. But they do not have a clear framework and methodology for understanding the concepts that they were able to better understand with this activity. A similar result emerged in Corrientes, where a participant pointed out that the Officials tend to work in a disorderly manner, and this game-exercise helped them to organise ideas and concepts: “*we’re working on this [climate change] every day. [...] But we’re working, perhaps, in a disorderly manner. This exercise gives us an order, coherence, which is what we technicians need [...]. It opens our mind to learn to have an organisation that is what sometimes is more difficult to us*”. This result was also identified in the specific literature, i.e. the games help the participants to think about specific planning decisions [8,38].

In case D, the oral feedback was consistent with the questionnaires of other case studies. Participants highlighted the fact that this kind of activities kept them active and made them think about the concepts, the specific problems they work with and potential future actions, as also detected by [39]. Moreover, some participants pointed out that the gaming approach was positively above their expectations and its practical component made them interested and lively, as also highlighted in the literature [11,12,13]. This activity, the potentialities to replicate it in other contexts were acknowledged in all the cases. In Corrientes, for example, it was said that: “*I think this exercise is very good for us to be replicated. Because many of us work in the public sector, and we have a lot to do with the population at risk and we have to know how to do these exercises, don’t we?*” Another intervention highlighted that the method “*is an exercise that helps us to reflect and incorporate learning in relation to what hazard, exposure and vulnerability mean ... and we can incorporate this exercise in the field we are doing our work*”. Another participant in Corrientes declared her will to replicate the method for sustainable waste management: “*what I take with me is to copy this approach for the treatment of solid urban waste, because I think the activity is very good to be replicated in our neighbourhoods and community centres*”. This latter comment is actually consistent with the existing literature, that highlight the usefulness of games to recognise the collective impacts of human activities on ecosystems [40,41], as well as to a more responsible use of natural resources [38]. In Guadalajara, the participants asked to keep their respective pictures, to be able to replicate the game with the rest of colleagues in their respective municipalities. In case D, they also underlined the opportunity provided by the exercise and training in general to share experiences and ideas and to set up new forms of collaboration. Some participants were also thinking to adopt this approach in other seminars as concluding or ice-breaking activity, as identified by [7]. However, despite the success of the activity *per se* as method, results show that the concepts were assimilated and connected differently in the four cases. In general, the participants of both cases A and B (Johor Bahru and Corrientes) performed better in the correlations of the key concepts of the adaptation framework than those in cases C and D (Guadalajara and Palermo). Even though the outcomes were similar, the participants of Johor Bahru performed better for the concepts “hazard”, “exposure”, and “vulnerability”, whereas the participants of Corrientes presented more matches for “impact” and “adaptation. Generally speaking, the concepts of “hazard” and “adaptation” seem to be better understood than “exposure” and “impact”, being “vulnerability” the concept with lower score. Vulnerability appears to be the hardest concept, especially for the case study run in Guadalajara. Vulnerability is frequently confused with exposure, bringing the necessity to

focus more on this concept in future activities by spending more time on its explanation. On the contrary, the adaptation actions are often well understood: many groups in the different regions and risks selected the pre-evaluated result. This is due to the fact that, as reported previously, many participants are already dealing with adaptation options in their daily work despite lacking an in-depth background in the topic. Feedback was provided during the presentation of participants to let them understand the mistakes and how to correct them. The participants of case A assimilated well the concept of “hazard”, having more difficulties to understand the concept of “impact”. From Fig. 4 it can be gathered that some risks and pictures are more straightforwardly understood than others; therefore, the concepts related to climate change adaptation are better (or worse) assimilated depending on the risk assigned to the groups. Two comments related to this fact were mentioned in Corrientes. For example, one group (with a full match of photographs) indicated that the exercise *“was a very practical and simple way to assimilate the concepts, more than anything because this specific topic, flooding, concerns us closely”*. Meanwhile, other group stated that *“drought is too complex to understand the concepts”*. This confirms that many factors can affect these results such as the background expertise and skills of participants, their knowledge of the territory, the risk under analysis, and years of experience. The time allocated to develop the exercise is a key feature. Perhaps, the cultural approaches of the regions can give a different perception of timing. As seen in Fig. 7, different opinions regarding time allocated to the exercise were given by participants of Johor Bahru and Corrientes: whereas 31% of respondents in Corrientes considered that the exercise was too long, 69% of the participants in Johor Bahru indicated the exercise was too short. Moreover, other methodological aspects may have influenced the results of the exercises in the four cases. For example, two out of four case studies (Johor Bahru and Palermo) were fully concentrated on adaptation, so participants had to focus on the adaptation topic only. While the sessions in Corrientes and Guadalajara dedicated both to mitigation and adaptation. However, the good performance obtained in Corrientes might give space to another possible explanation related to the experience and expertise of participants. Finally, in Palermo a great number of participants were external experts that are used to study and keep themselves up to date to support local authorities in engineering fields. The high-skill background of participants in Palermo makes their results inconsistent, since their performance was not among the best. Participants, however, were not experts in adaptation, but on mitigation, having worked in the Covenant of Mayors framework with the 2020 emissions target and only recently addressing the climate change adaptation pillar.

CONCLUSIONS

Citizens in general and officials from municipalities in particular are in need of tackling adaptation to climate change. The lack of a global understanding of the concepts regarding the adaptation framework can make climate adaptation action more complicated. As scientific body supporting the GCoM, the JRC is in charge of developing capacity-building activities. During the first phase of the implementation of the initiative, it was noticed the need to strengthen the knowledge on the basic concepts of the adaptation framework. Therefore, the game approach adopted in the training was developed to address this gap. It was implemented to enhance the assimilation and integration of the basic concepts and their implications in their territories, through the visualisation of the concepts and their relations. Along different workshops conducted in four different regions of the world (North America, Latin America, South East Asia and Europe), the reaction of the participants was similar: high interest and motivation in participating in these processes. The activity allowed the participants in relating the IPCC concepts of climate adaptation with the daily practical issues they are used to deal with. One of the key outcomes of the activity was the capacity of enabling the participants to identify the key elements for the assessment and planning of climate change adaptation while organising them in a coherent way. This activity resulted in a structured approach for climate change adaptation that is rooted in prevention, forecasting and monitoring systems instead of the traditional emergency reactive approach. Regarding the performance of the exercise, several factors influenced the results obtained albeit the establishment of homogeneous groups. The main factors are: the group components, previous knowledge on the topic, the knowledge on a specific region, the risk evaluated by the groups, and the images selected for every exercise. All these factors strongly influenced the answers of the participants and therefore need to be reviewed in order to eliminate possible biases. However, results indicate that, on the one hand, the concept of vulnerability is the most complicated to assimilate by the participants and, on the other hand, the understanding of climate risks also depends on the type of risk tackled. Overall, the perception of the application of this game-like approach to climate change adaptation has the potential to strengthen the basic knowledge on adaptation to climate change, or other environmental management issues, and to enhance the decision-making processes.

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^a Eventually, the concepts of maladaptation [42] and adaptigation [43] can also be used in the game if necessary.

^b Risk is not considered in the game since; following Table 1, it is the probability of occurrence of a hazardous event, being, therefore, a number that cannot be represented by a photography. In fact, a risk is a function of hazard, exposure and vulnerability.

^c <https://www.ipcc.ch/report/ar5/wg2/>.

^d One additional group of three people had to be improvised in order to not surpass 10 people per group, as well as to not repeat the same profile in the groups.

^e The matches are used to present similarities and differences among regions. The pre-evaluated solutions proposed by the authors of this paper do not necessarily have to be a unique solution, although the photographs were prepared so that only one solution could be possible.

FIT-BYTES: REIMAGINING THE SUPERMARKET THROUGH THE LENS OF HEALTH

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ABSTRACT

Supermarkets have a stronghold on the United Kingdom's (UK) grocery market; as such, they function as the main interface between urban citizens and food supply. Based on a nested model of convenience, the fifty-year dominance of supermarket shopping has reshaped cities and resulted in the deterioration of citizen health through issues of access, transparency and choice. Visualising how supermarket shopping impacts citizen health; from the scale of the city to shelf, may be an effective strategy to reimagine healthier systems and spaces for the future. This study applies a research-by-design methodology to visualise and reimagine supermarket shopping through the lens of health. A propositional, health-focused supermarket, named *Fit-Bytes Market*, is designed using systems thinking and STEEP scenario-building techniques. Loosely based in Belfast, UK, the propositional supermarket is visualised through simple 'from-to' diagrams and descriptive photomontages. Together, these drawings function as tools to interrogate current relationships between urban citizens and food, and roadmap key urban and architectural moves to holistically embody health in future relationships. This study's results suggest that if urban food shopping shifted to a health-centric model, wider relationships between citizens, food and the city would fundamentally embody health as a result. It also discusses the framing of health and considers the interdependent relationship between citizen and planetary health.

KEYWORDS

supermarket, research-by-design, health

INTRODUCTION

Designed with convenience in mind, the fifty-year dominance of supermarket shopping in the UK has contributed to the deterioration of citizen health through issues of access, transparency and choice. Supermarkets arrived in the UK after WWII, coinciding with the Americanisation of Europe, coupled with a general flight from the city and growing car and fridge ownership (Steel, 2013, Lyster, 2017, Dennis and Urry, 2013, Rees, 2015) The rising affluence afforded by the post-war era also supported the growth of a consumer culture which created ideal conditions for supermarket-style shopping across the UK from the 1970s onwards (Freidberg, 2009).

Today, there are two key supermarket typologies and nine dominant retailers within the UK (Statista, 2021) (Fig. 1.). The first and most widely understood typology is that of a ‘big box store’ which is strategically located on the edge of cities next to key arterial road infrastructures. Usually difficult to access without a car, these stores act as one-stop-shops servicing a GIS-generated territorial zone of customers (Le Cavalier, 2016, Lyster, 2016). Sometimes standalone, they can become anchors to small enterprises or fill an anchor position within a multi-tenant shopping mall. The second, much smaller, supermarket shopping type sits within or next to urban high streets. This type emerged in the mid-1990s in response to the oversaturation of out-of-town shopping and tightening of UK planning development laws (Steel, 2013, Seth and Randall, 2011). This type sits outside of the grocery market and is classed as a form of convenience retail. While still designed as a one-stop-shop, these stores tend to sell goods at a significantly marked up price to a hyper-local consumer demographic (Walsh, 2021). Designed for quick and easy access by car or on foot, both models have reshaped the city, aisles and shopping baskets impacting citizen health as a result.

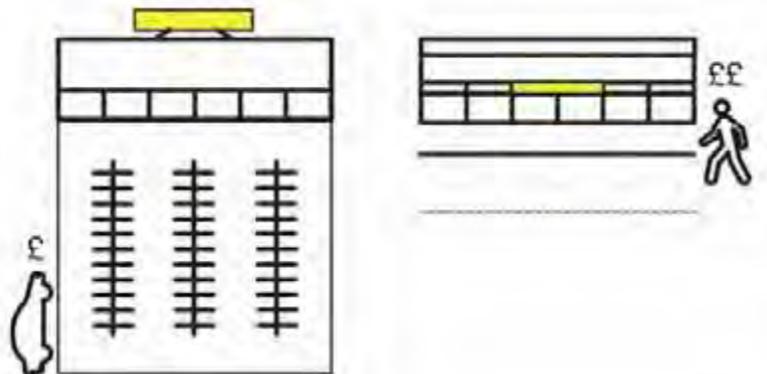


Figure 1. Two diagrams comparing the out-of-town (left) and high-street (right) supermarket types.

As the key food shopping type in the UK, supermarkets are the primary interface between the UK’s consumers and the food they eat. The location of supermarkets dictates physical as well as economic access to food while the one-stop-shop model has proliferated an increase of added-value processed food product lines. Despite this, relatively little has been written about the impact of the urban and architectural design of supermarkets on citizen health. Existing studies at the urban scale analyse walkability and map the prevalence of urban food deserts (Franck, 2005, Keeffe, 2016, Thibodeaux, 2015). While architectural studies focus on the relationship between retail layouts and shopping behaviours (Boyd, 2012, Chung et al, 2001, Kirby, 2008) Although these studies generate a focused view of the negative impacts of supermarket shopping on health, they do not discuss how the design of supermarkets impacts consumer choice or offer cohesive design solutions to improve shopper health. Understanding how the design of supermarkets impacts citizen health and re-imagining a shopping model to embody health may be an impactful route to improve the health of the UK’s population quickly and effectively. Approaching this design challenge through multi-scalar analysis of supermarket shopping’s impact on citizen health and the application of research-through-design methodologies, new possibilities for a healthier future for food-retail might be gleaned.

To date, no known study redesigns the supermarket shopping model to embody health. Accordingly, this paper reviews the ways in which supermarkets impact citizen health and proposes a new vision for supermarkets to promote health. Looking at the scale of basket, aisle and city, and the anatomy of self-service, this study provides big-picture analysis of the current system, based on convenience, speed and impulse. This is compared with the emerging relationship between data and health in the food shopping experience. Finally, taking these insights, Belfast, UK, is identified as a case study to reimagine a holistically healthier future supermarket. While place-based, the results seek to provide a transferable hierarchical blueprint for healthy urban food shopping.

THEN NOW NEXT: VISUAL RESEARCH-THROUGH-DESIGN

This study employs an experimental research-through-design methodology and applies systems thinking to unpack and reimagine health in the food shopping experience. Cross (2007) defines the actions of design research as a process of framing problems to generate solutions, where there can be numerous right answers. Sitting with an ontological, heuristic paradigm, this approach is solution rather than problem focused. Groat and Wang (2013) suggest that design-research merges the qualities of design and research disciplines, resulting in a time-based approach formed of systematic analysis of the past and present and generalisable propositions on the future. This study applies Schon's model of reflective practice which highlights the iterative nature of design by breaking the process into three distinct parts; frame, move and evaluate (Schon, 1983)

Framing allows the designer to set out a framework for progression, sets the thematic brief for the design move and informs the success of that move in the evaluation phase before informing the tone for the next iteration. This study is framed under the theme of citizen health across the three stages of the design process. This approach allows consideration of the theme across time. STEEP analysis, standing for social, technological, ecological, economic, and political, supplements the thought process across the design stages. The main research questions driving this paper seek to explore the past, present and emerging future picture of citizen health and its relationship to supermarket shopping; *How has the supermarket affected citizen health in the last fifty years? How do supermarkets change urban shopping habits? How does the aisle and basket impact consumption? What technologies, behaviours or policies are likely to change this dynamic in the future; and what would that look like embedded in a new shopping model?* Design is typically understood as the middle stage of Schon's model, but before it can happen, designers need to know how to move, highlighting the importance of framing first. Design takes the findings from framing to make this move or a leap. In the field of architecture and urbanism, this leap normally means the design of a space within a physical context. Like framing, the leap can consider different scales and timeframes. A patchwork of micro-moves bridging scale and time, such as a view of a future aisle, a location map in the city or an image of new packaging, ease friction between the frame and move stages, eventually building up a clearer picture of the bigger move, in this instance a 'healthy' supermarket.

Evaluation is the final stage in Schon's model of reflective practice. Reflecting back on the thematic framing, the designer can assess the success of the move. Kolodner and Wills (1996) suggest that evaluation of proposed solutions triggers the problem and solution to co-evolve in the design process. In this study, secondary research questions emerge out of the initial framing exercise which could inform the trajectory of future design iterations. These questions are considered in the conclusion of this paper; *Did the move address the theme of citizen health? How could the proposal be healthier? Should 'health' be redefined?* Evaluative questions can filter back to adjust the framing as well as the design move in the next full design iteration.

Drawing functions as the primary output at each stage of the research-through-design process combining analysis, synthesis and ideation across time, scale, and context. A traditional output in the field of architecture and urbanism, drawing generally performs two roles: to think through and to communicate with. The flexible nature of this medium means that ideas can be communicated quickly or slowly, in or out of context.

This study leans on the EU-funded CityZen Roadshow (2019) methodology which uses diagrams and collages to move quickly through design iterations. Diagrams work as 'explanatory devices', capturing the immediate and generative ideas produced around the theme of health in a simple way (Allen, 2012). Collages communicate a 'moment in time' combining real-life context and health-focused interventions which is an effective way to critique the proposal's potential impact. Maps, matrix and orthographic drawings supplement the study to think about and communicate what is, what was, and what could be.

SUPERMARKETS AND CITIZEN HEALTH: SCALES-ANATOMY

Basket-scale

Poor diets caused by processed, convenience foods contribute significantly to the state of the UK's public health. Today, just over 7% of deaths in England and Wales are due to an elevated body mass index (BMI). These BMI-related deaths cost around £2.47 billion per year and around 1.8% of the NHS budget (Tovey, 2020). This doesn't factor in the cost of other diseases largely affected by a patient's diet such as certain cancers, diabetes and cardiovascular disease (Health matters, 2020). In a country where two thirds of the population are overweight or living with obesity, the pandemic has prompted the government to release a food-centric obesity strategy (Obesity Strategy, 2020). Since 1947, data relating to the UK's consumption preferences

has been published annually in the Representative Price Index (RPI) Basket of Goods (BOG). Designed to gauge shifts in inflation, mapping the goods entering and leaving the basket over time indicates the rising popularity of convenience foods (Fig. 2.), for example, loose tea replaced teabags in 2002, while in 2018, stoned fruit were removed from the basket altogether (Consumer price inflation, 2021).



Figure 2. Visual timeline analysis of 'Basket of Good' trends in UK food consumption.

Self-Service-Anatomy

Designed initially for the bulk-buying of long-life food in 1930's America, the shift from local and fresh to global and processed can be attributed to another shift from counter to self-service; all designed to save consumers time. Before it, shoppers prepared a list, waited to be served, then watched as their groceries were weighed and bagged on their behalf (Bowlby, 2000). Combined with the growing popularity of pre-packaged food, self-service changed the relationship between consumers and food, effectively removing the 'middleman'. Breaking the relationship between consumers and shop employees, self-service allowed supermarkets to expand indefinitely to host thousands of products. This fueled a re-siting of food-retail to the edge of the city, and in doing so, transformed the home into a store for food as well as a place to prepare and eat it. A modernist phenomenon, self-service also removed the social dynamic of shopping, reframing it as an activity to be streamlined to achieve convenience. Aisles, trolleys, barcodes, and checkouts are some of the spatio-technological outputs of this objective.

Aisle-scale

Convenience masks two further objectives in the supermarket shopping type; to facilitate disconnection and stimulate impulse (Chung et al., 2001). Bowlby compares the supermarket aisles to a prison, labyrinth and jungle, trapping shoppers inside as they lose track of time or location (Bowlby, 2000). In *Learning from Las Vegas*, Venturi, Scott Brown and Izenour (1977) describe the similarly trapping effects of casinos; without windows and artificially lit, time is 'stretched and bent'. Through the application of psycho-programming techniques, a form of psychoanalysis developed to sell commodities, shoppers are tempted to buy more than they really need. In retailers such as LIDL, displays play on the human senses, with freshly baked bread placed near the entrance and alcohol and sweet treats near the checkouts. At the scale of the shelf, planograms dictate the placement of products so that high-profit products sit at eye level where they are most likely to be picked. Blythman's (2004) description of the supermarket aisle display as a 'permanent global summertime' reveals how the elimination of seasons and scarcity has led to a hyper-normalisation of luxury. In the readymeal aisle, product ranges and packaging reflect shopper desires; to lose weight, to treat oneself, to be less impactful on the environment, all within a convenient and quick meal-sized package.

City-scale While there is a growing demand for supermarkets to be located on high streets, out-of-town shopping remains the dominant model. Strategically positioned along busy road networks, large 'totem' signage borrowed from the North American tradition, are designed to be read at speed and form a key component in the supermarket's impulse architecture (Fig. 3.). Combined with car parking, the car-boot is the final set-piece to ensure a convenient shopping experience as well as unlimited purchases (Humphrey, 2012). These deep-rooted connections between supermarkets and cars detrimentally impact urban shopping access. Using yellow dots to map the prevalence of supermarkets in Belfast in relation to residential neighbourhoods, it's clear how much of the city is a food-desert (Fig. 3.). Those with a car can visit more than one retailer within a five-minute drive, this is indicated with the larger dashed circles on the map. While only a limited number of residents can walk to a supermarket within ten minutes, this is indicated by the darker circles on the map. Drawing aerial views of Belfast's supermarkets further demonstrates the impact of carpark and store scale on active travel (Fig. 3.). Dedicated parking to the front of the building, which is often fenced at its boundary, deters active travel and blocks pedestrian access from nearby housing.



Figure 3. Mapping supermarket infrastructures in Belfast, UK

FOOD AS MEDICINE, SHOP AS CLINIC

RPI-BOG trends over the last decade indicate that consumers are becoming more concerned with health (Fig. 2.). To some extent, supermarkets are responding to this by marketing new ‘added-value’ health-food ranges, such as ‘Be-Good-To-Yourself’ readymeads and fat-free alternatives. That said, health is not yet embodied in the experience at any other scale and remains a conscious choice for consumers to make (Shore Capital, 2020). Making healthier food choices while food shopping remains difficult; but by reframing food as medicine, the supermarket could become a bit like a clinic. Today, medicine tends to be prescribed on a case-by-case basis on the premise that it improves a patient’s health and the type and dose of medicine corresponds to personal markers in the body. This approach might be applied to food shopping through personalised ‘filtering’ of the experience to enable health (Kelly, 2017).

This concept of ‘filtering’ has already started to be explored, for example, Ratti’s *Supermarket of the Future* installation at Milan’s 2015 World Expo stages an experience around data filtering. Large-mirrored screens fixed above the grocery aisle replace the role of packaging to communicate data relating to unpackaged produce below. Despite the environmental benefits of this design intervention, next generation screens of this kind could create an educative experience if they filtered data for each individual consumer. Filtering is already commonplace in the online shopping experience. Augmented Reality (AR) shopping apps such as IKEA Place allow prospective consumers to visualise an item of furniture in their room while Nike Fit enables consumers to measure their feet to order the correct size (Indigo9 Digital, 2021). Similarly, subscription style food businesses such as meal-box provider Gousto allow customers to tailor a weekly order to meet their taste preferences and dietary restrictions. What binds these examples is the agglomeration of data and experience. Where supermarkets emerged and developed to provide an efficient service, today’s shoppers expect an experience. Detailing the key moves from former to latter, Pine and Gilmore (1998) suggest the user is reframed as a guest transforming the experience from standardised to personalised. This is echoed in Make Architects’ (2019) report on retail, which suggests that the ‘sales per square foot’ metric will be replaced by measurement of potential consumer engagement, recruitment and retention over time. This is a current focus for large anchor retailers like John Lewis and Selfridges who began to convert sales spaces for coffee-tasting, manicures and cooking demonstrations last year (Wood, 2020). In food retail, this shift is also evidenced in the resurgence in popularity of experience-based food markets across the UK.

Reprogramming the supermarket as a clinic would require the interfacing of different kinds of existing health data into the physical shopping experience. Supermarkets are already experienced at data mining and consumer profiling on an individual basis. Store loyalty cards record every purchase made as well as near-purchases online; this could be used to create a nutrient and calorific profile of consumer purchases. Combining this data with medical health records could close loops to understand and optimise citizen health. This type of data collection is already commonplace in health-tech where fitness apps and smart watches monitor movement, heartrate, sleep and blood pressure. Knowing the health, fitness and consumption data on an individual basis could completely change the future food shopping experience at every scale.

PROPOSITION: FIT-BYTES MARKET

After combining the core theme of health and emerging trends in data personalisation and experience the question of how this will impact the future of shopping remains. There is no structured route to move from problem framing to solution generation but thinking about the existing conditions of food shopping as a multi-scalar system can be a helpful place to start.

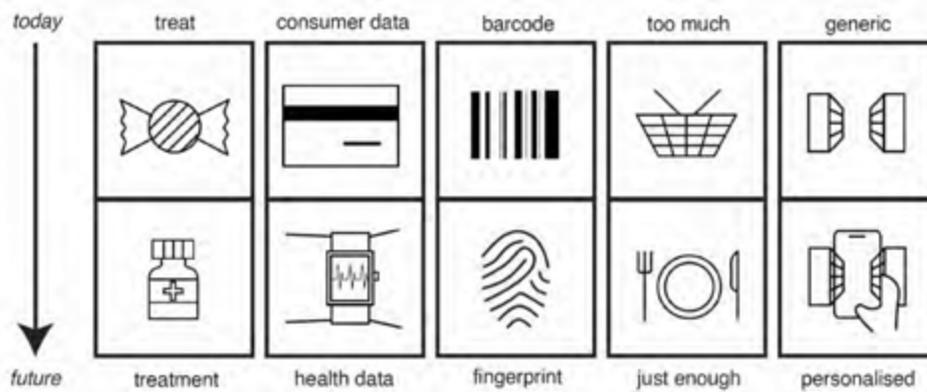


Figure 4. 'From-to' diagram matrix exploring how supermarkets might become holistically healthier.

The from-to diagram matrix (Fig. 4.) enables piecemeal analysis as well as ideation on how supermarkets might enable citizen health. By embodying health, the consumer could be reframed as a patient, while food becomes a form of treatment. Reframing the purpose of data to improve health, the barcode might be replaced by a fingerprint, syncing health data to reward healthy behaviours. Finally, filtering health on an individual basis would allow shoppers to make informed and personalised choices.

Read together, the matrix indicates that a holistically healthy supermarket would operate very differently to the existing model. What is clear is that unhealthy lifestyles significantly burden the UK's health service which is largely reactive than proactive. a shift from reactive to proactive 'healthy' With that in mind, what if future supermarkets became an extension of the UK's preventative healthcare service? The proposition below, 'Fit-bytes Market' imagines that a healthy supermarket shopping model would roll out across UK cities in two stages; first as a network of healthy readymeal vending machines in the NHS' estate of hospitals and GP surgeries, then as a number of markets strategically placed next to healthcare and fitness sites. The next section explores the Fit-Bytes Market proposition in the case study city, Belfast, UK.

City-scale

Fit-bytes Market emerges in urban sites within walking distance to residential neighbourhoods in Belfast (Fig. 5.). To encourage active travel, car parking is kept to a minimum and ample bicycle parking is prioritised. Shoppers are also encouraged to buy little and often or avail of a bicycle delivery service to mitigate driving to shop. These urban siting decisions improve consumer health and encourage planning ahead which limits over consumption. Co-locating of the Fit-bytes Market next to other health focused spaces, such as leisure centres, running tracks and gyms further facilitates further 'passing trade' for healthy shopping habits.



Figure 5. Collage of Fit-bytes Market at city scale

Aisle-scale

Inside the market, shoppers can exchange health data to receive personalised diagnostics and a tailored shopping experience which recommends the best foods to promote health. Aisle space is carved away to host diagnostic booths where consumers receive progress reports and shopping advice. Unlike supermarkets today, aisles mainly host whole foods, while processed foods are replaced by healthy readymeals and meal boxes. The shopping experience replaces impulse with mindfulness. As shoppers move through the market, they receive nudges and suggestions helping them to pick better foods and track the effectiveness of shopping decisions.



Figure 6. Collage of Fit-bytes Market at aisle scale

Basket-scale

Replicating the thriving experience of a market hall, a host of healthy readymeals may be consumed on site. While rentable kitchens and cookery classes further facilitate the development of better relationships between consumers and food. Whether prepared, part-prepared or whole, consumers are encouraged to buy no more than a basket which helps them to keep track of what they buy and how they eat. On payment, the store loyalty card generates reward points which, rather than promote further consumption, may be used to avail of other health and fitness services such as gym memberships or mindfulness courses. Vitally, aisle, basket, package, barcode and checkout focus less on speed and impulse and more on engagement and education, reframing food shopping as an important and worthwhile focus of time and energy.



Figure 7. Collage of Fit-bytes Market at basket scale

Healthy boundaries

Through the scales of basket, aisle and city, and analysis of the anatomy of self-service shopping, this paper unpacks and repacks the supermarket through the lens of health; reviewing how they impact citizen health today and how they could impact it in the future. As a key food shopping interface in UK cities, the research-by-design methodology and various drawing techniques, reveals potential moments of acupuncture to shift towards this goal; changing the type of food sold, the display of food, packaging, interfacing and connecting with complimentary activities within the city.

Jumping from framing to designing, from idea to space, will always reveal further design problems. By starting with the question of how a healthier supermarket might emerge, the themes of citizen health, personalisation, data and experience are explored on the premise that the supermarket shifts from a being private business to a public body. If run by a public health service, there would be a risk that food becomes weaponised and citizens are penalised for buying less healthy foods. Providing a service based on fitness, health and food data could revolutionise citizen health but this would have to be achieved by incentivising better choices without fear of punishment. Fostering learning and empowerment through a personalised shopping experience may be the best route to this end. Defining the boundaries of influence, and as such, exploring the ownership structure and ethics of such a shopping service would be vital in future iterations of this idea (The Guardian, 2021).

Though this proposition focuses on attaining citizen health, it's important to reflect on the type of citizen it addresses. Designed to promote active travel, this supermarket could only positively impact the health of urban and peri-urban citizens. Those living in rural conditions would likely rely on a different kind of supply model not explored within the scope of the study. Additionally, the proposal only considers the health of UK consumers and those who normally shop in supermarkets. Reflecting on the definition of health opens further questions about the proposal. Reframing the definition of citizen reveals the imbalanced benefits of provision – designed just for people living in urban and peri-urban locations in the UK. Though left undiscussed here, global sourcing practices continue to outsource negative impacts on citizen health beyond the UK's boundaries. Those who grow and process food often face unhealthy working conditions while citizens in those places faces issues of pollution and resource scarcity. A good example of this is the recent growth in popularity of healthy foods such as avocados; healthy for consumers, but when intensively produced, negatively affect wider citizen health. Sourcing practices also impact planetary health, of which human health is wholly interdependent. Importing globally produced healthy foods exports and hides environmental damage. This system also leads to the production of waste at the point of consumption which tends to be managed elsewhere. Today, urban citizens rarely see the global impacts of this system and may be even less inclined to in a supermarket that promotes human health above all else. This proposal takes a siloed approach to health and largely ignores systemic impacts on planetary health, thus reinforcing the supermarkets opaque interface between spaces of consumption and production. Prioritising planetary health, and citizen health under this, new iterations of this proposal would look and operate very differently. Breaking down this interface might be a good start in future iteration of this design problem

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TOWARDS A SOCIALLY EQUITABLE APPROACH TO URBAN RESILIENCE ASSESSMENT

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ABSTRACT

Effects of COVID-19 Pandemic highlights a systemic gap in our understanding of urban resilience and the critical need to rethink how resilient cities are defined, measured, and (re)built. Current research and resiliency models overemphasize the environmental, institutional, and infrastructure aspects of urban resilience. In contrast, the social and economic structure and processes are neglected, resulting in cities being unprepared to deal with extreme events. This research conducts a multidisciplinary systematic review of the literature on urban resilience assessment to determine the extent to which current knowledge addresses social inequity to prevent disasters from striking communities disproportionately. We also examine whether these tools provide instruments for cities to create an agile urban economic system that can withstand climate crises or pandemics to 'bounce back' to previous equilibrium points or 'bounce forward' towards new paths through innovation adaptation. We systematically studied 130 papers from the Scopus and Web of Science (WoS) database using a science mapping technique named VOSviewer, a widely known software tool for bibliometrics analysis and scientometric visualization. We employed the Qualitative Content Analysis (QCA) method to recognize the dimensionality and the spectrum of different indicators and assessment tools. Analysis of the urban resilience literature and assessment tools reveals that most of them fall short of appropriately emphasizing the core social and human systems as enablers of resilient cities, and further improvements are required. This study argues for assessing resilience against socio-economic risks and presents a novel urban resilience assessment and modeling toolkit integrating social and behavioral, technological, and environmental dimensions of resilience.

KEYWORDS

Urban resilience; Social equity; Planning; Urban sustainability; Systematic review

INTRODUCTION

Urban resilience planning has become a critical topic of discussion among governments, researchers, and the general public, owing to growing concerns about climate change, an increase in the frequency of natural disasters, and the ongoing COVID-19 public health crisis. With an estimated 90% of all COVID-19 cases reported, urban areas have become the pandemic's epicentre [1]. Global cities such as New York, Mumbai, and London are bearing the brunt of the crisis, with many suffering from strained health infrastructure, deteriorating public transportation systems, and economic consequences that extend well beyond their borders. Cities are particularly vulnerable to virus spread due to their population size and high level of global and local interconnectivity [2]. For many cities, the COVID-19 pandemic has morphed into a crisis of urban access, equity, unemployment, public services, and well-being, which disproportionately affects the most vulnerable members of society [3, 4]. The International Monetary Fund estimates that a global pandemic would cost \$28 trillion and would result in the permanent loss of 120 million jobs in the tourism industry alone due to severe shocks to the global urban economy [5]. The debate over social inequity as a barrier to urban resilience has intensified in countries such as the United States—where approximately one in five counties is disproportionately black, accounting for 52% of COVID-19 cases and 58% of deaths [6]. The current challenges prompt us to consider our communities, cities, and regions' resilience to emerging shocks. Recent evidence demonstrates a systemic gap in our understanding of urban resilience, and additional research is required to (re)build definitions, models, and approaches for risk assessment and capacity development.

The term “resilience” first appeared in the scholarly literature in the early 1970s and is generally defined as a system's capacity to recover from a specific shock (social, economic, environmental, infrastructure, or government) [7]. The Rockefeller Foundation (2016) defines resilience as an area's capacity for individuals, communities, businesses, and infrastructure systems to survive, adapt, and grow, not only in response to shocks but also to daily or cyclical stresses that erode local capacity. Urban resilience as a development discourse focuses on the capacity of urban populations and ecosystems to adapt to changing environmental, social, behavioral, and economic conditions [8]. Urban resilience has been prominently discussed in discussions of sustainable development and climate change. However, there is considerable uncertainty regarding whether the concept refers to the community's capacity to recover from a shock or to the degree of resistance to the shock in the first place. Recent studies define urban resilience as a process of continuous development in which communities and social systems evolve and adapt in order to constantly reinvent themselves and bounce back from crises, rather than aiming for stability [9]. There is also recognition in the literature of the fact that existing resilient city models place an excessive emphasis on environmental, institutional, and infrastructure components. By contrast, social structure, knowledge systems, and behavioral aspects are overlooked [10, 11], leaving cities and local communities unprepared to deal with extreme events.

This research undertakes a systematic review from a multi-disciplinary perspective to examine to what extent the urban resilience assessment frameworks and literature engage with the underlying social disparities? This article explores which additional criteria are to be adapted in the existing resilience frameworks to build an integrative urban resilience assessment toolkit. The paper is organized into four sections. Section 2 describes the overall analytical framework and the review methodology. Section 3 presents the search results of the systematic review, including a description of the urban resilience literature temporal and geographic analysis. Finally, section 4 discusses the importance of the findings and proposes a toolkit for a socially inclusive urban resilience approach. Limitations and research way forward are discussed in the conclusion.

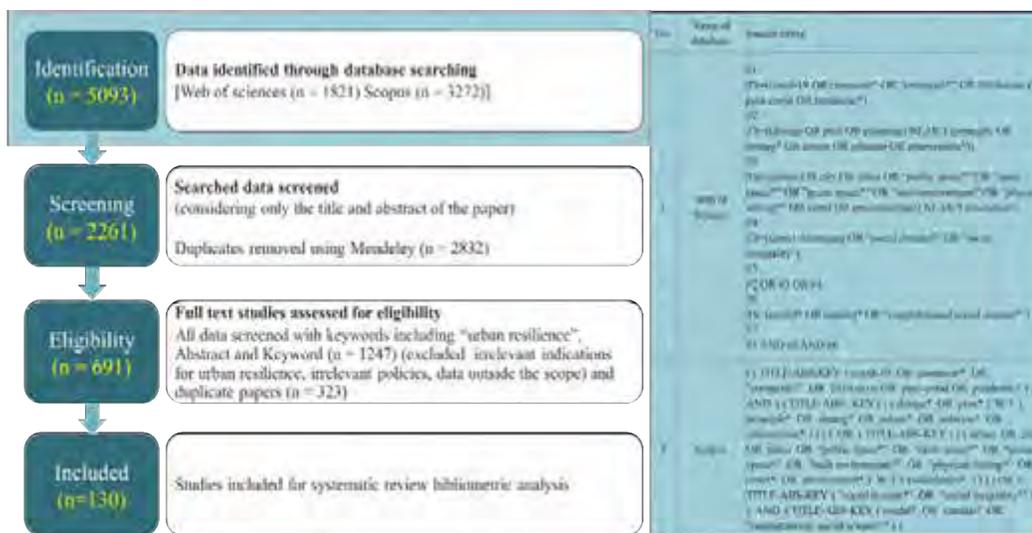
MATERIAL AND METHODS

The current state of the art in urban resilience is reviewed, with an emphasis on a diverse set of policy documents, book chapters, journal articles, websites, and manuals. Following a review of the literature, a Qualitative Content Analysis (QCA) method is used to identify various themes/categories associated with multiple dimensions of urban resilience [12, 13]. These dimensions are environmental, economic, social, cultural, political, technological, and institutional, and they are assessed by compiling a list of standard resilience criteria from various sources. According to our review, urban resilience is conceptualized as the interaction of three model factors: environmental and economic models, social and behavioral models, and technological models. This review identifies various characteristics/indicators of these models and dimensions, as well as significant models and parameters.

We conducted a systematic review of the literature in accordance with the guidelines for “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) [14, 15]. PRISMA was designed primarily for the purpose of conducting systematic reviews of health interventions. It can, however, be used for other types of research, including social sciences, and is

gaining popularity in fields such as urban planning, design, and architecture. The systematic review was conducted in six steps in accordance with the guidelines: 1) initial searches, 2) study identification, 3) title and abstract screening, 4) full-text review for eligibility, 5) data extraction, and 7) data analysis, findings, and discussion.

The entire process consisted primarily of two steps: database creation and analysis using the VOSviewer software. We began our search for literature with Google’s general search engine, then moved on to Web of Science (WoS) (1821 documents) and Scopus (3272 documents) to capture additional sources. Using the advanced search function of the WoS and Scopus, the search string was utilized to retrieve the data. The terms included ‘design OR plan OR planning,’ ‘urban OR cities OR public spaces,’ ‘covid-19 OR coronavirus OR post-covid OR pandemic’, ‘social inequality.’ Through various search engines, a total of 5093 records were identified and imported to Mendeley for the automatic removal of duplicates. Subsequently, 2832 duplicates were removed at this stage. The review limited its data search to peer-reviewed articles and frequently cited practitioner-based assessment manuals. This procedure resulted in the selection of 691 articles/studies (691 out of 2261) for additional systematic review, each of which was subjected to a Qualitative Content Analysis (QCA). These are further evaluated for eligibility to include studies using comparable frameworks to develop a novel methodological system for assessing urban resilience. In the final stage, a total of 130 references were incorporated into the Qualitative Content Analysis. The systematic review of the literature and data extraction process is depicted in Fig. 1 using the PRISMA flow diagram.



*PRISMA – Preferred Reporting Item for Systematic Reviews and Meta-Analyses

Figure 1. PRISMA of the systematic review process.

All the 130 studies were imported into VOSviewer for science mapping and bibliographic analysis. VOSviewer is a widely used graphical user interface tool for creating bibliographic networks of journals/articles, publications, and countries and for citation, co-citation, and co-occurrence analyses [16, 17]. The tool is advantageous for identifying critical research areas and significant clusters in the assessment of urban resilience. The most influential countries in the field of urban resilience were identified, and their relationships were visualized using bibliographic coupling analysis by country. The sizes of the nodes, clusters, and links displayed in the graphic output are proportional to the frequency of the objects considered (e.g., keywords) and the strength of the connections between them.

RESULTS

This section summarizes the results from the bibliometric analysis of 130 studies included in the analysis. We analyzed the data about publication trends, categories or field labels, source country by author and case studies location, co-citation, and term co-occurrence. We build a conceptual network visualization with nodes & linkages using the keywords from the selected publications. We also perform a full-text analysis of the selected documents to create a co-occurrence network highlighting core areas and interrelationships between concepts of urban resilience. The final set of results reported here focuses on the dimensionality of resilience research highlighting researchers’ emphasis on social, cultural, behavioral aspects of urban resilience versus the importance laid to technological systems, environmental, and governance issues.

We find that the frequency of publication covering urban resilience topics has increased substantially since 2018. While less than four papers were published on average per year between 2010 and 2015, the same rose to 25 publications per year from 2018 to 2021. The most significant recorded numbers were observed in 2019 (29) and 2021 (28). Based on the WoS and Scopus field categorization of published articles, our analysis shows that a large majority of papers were categorized into environmental sciences (76), environmental studies (43), and green sustainable science technology (42) domains. Articles were categorized in moderate to high frequency into the fields of water resources (29), meteorology and atmospheric sciences (23), geosciences (21), and ecology (20). We find that very few papers fall into the domain of multidisciplinary sciences (5), and none were grouped under social sciences or humanities.

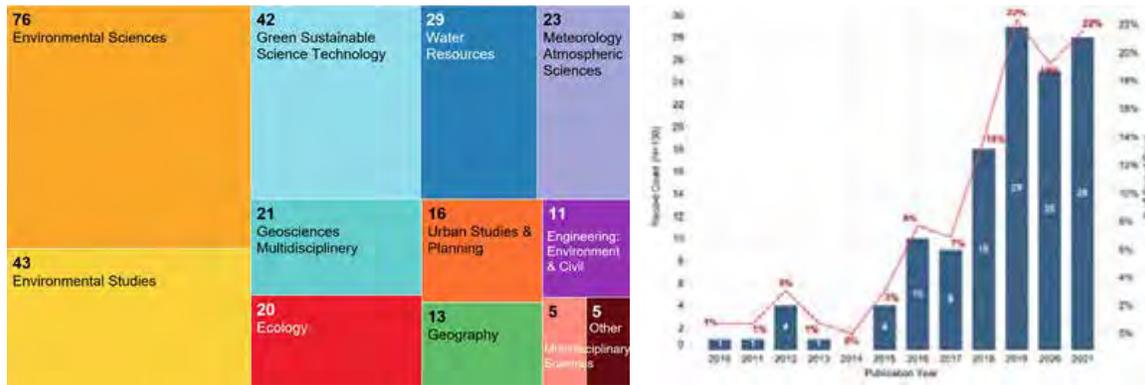


Figure 2. Publication frequency by categories and year

Figure 3 illustrates the geographical mapping of the countries that appeared in the included studies. Our analysis shows that the researchers in the United States and China produce the bulk of urban resilience-related research, with 28 (21.54%) and 27 (20.77%) papers published respectively out of the 130 samples studied. These two countries are followed by England (13, 10%), Portugal (10, 7.7%), and Italy (9, 6.9%) that show a great deal of emphasis on resilience studies. On average, 6 to 8 titles originated from Spain, Canada, Netherlands, France, Belgium, and South Africa. Countries with 3-4 publications on urban resilience and associated themes include Australia, Israel, Japan, Mexico, Germany, Singapore, South Korea, and Switzerland. Regions such as Brazil, Chile, Denmark, Norway show two articles per country, and one piece each came from Nepal, Poland, Slovakia, Costa Rica, Ireland, Cambodia, and Austria. Many countries facing severe urban resilience challenges in South Asia, East Asia, and Africa did not feature in this list.

Figure 3 also presents our analysis of the research connectivity between countries based on the number of publications, citation loads, and the derived link strengths using information from the WoS database. We find that the 28 documents published by researchers in the USA received 1390 citations, which is far greater than 94 citations received on 27 papers published from China. We find that some countries had fewer articles but received very high citation counts. For example, just six titles from South Africa received 308 citations, and five articles from Sweden were cited 335 times. Overall, the United States had the most substantial link strength of 136, followed by China (85), demonstrating their global research networks, outreach, and impact.

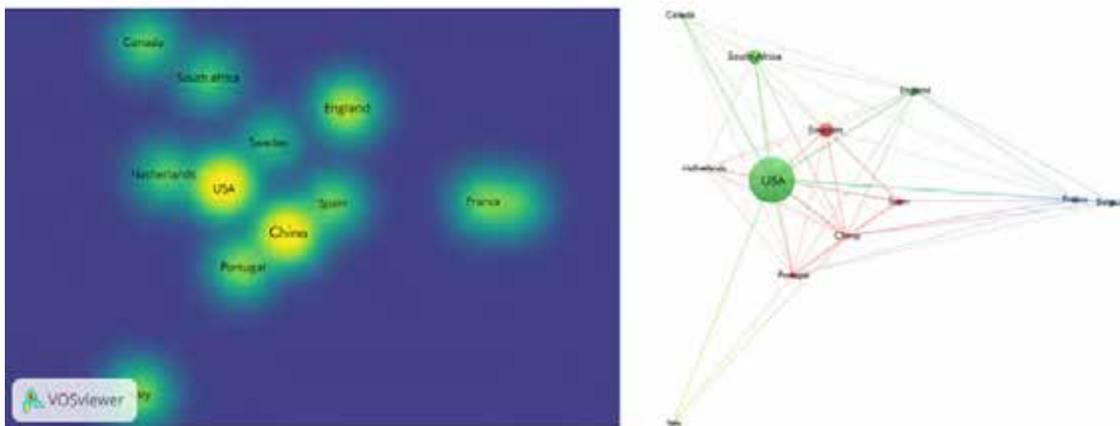


Figure 3. Publication records by countries and researcher networks.

We performed a keyword extraction and full-text analysis of the selected documents (n=130) to create a co-occurrence network highlighting core areas and interrelationships between concepts of urban resilience. The term “co-occurrence” refers to a technique for conducting bibliographic analysis that identifies major themes and topics/sub-topics that frequently co-occur and can thus be considered thematic clusters. In Figure 4 and Figure 5, the nodes and linkages of the keywords extracted from the abstracts of the included papers and the co-occurrence network derived from the full-text analysis are visualized. The size of each node is proportional to the number of times the term has been used. Proximate nodes are connected more closely, and the thickness of the links that connect them is proportional to the strength of the connection. Figure 4 also presents a timeline of keywords appearance showing that in recent years since 2019, there has been a significant move towards indicator-based assessments, ability considerations, and impact modeling.

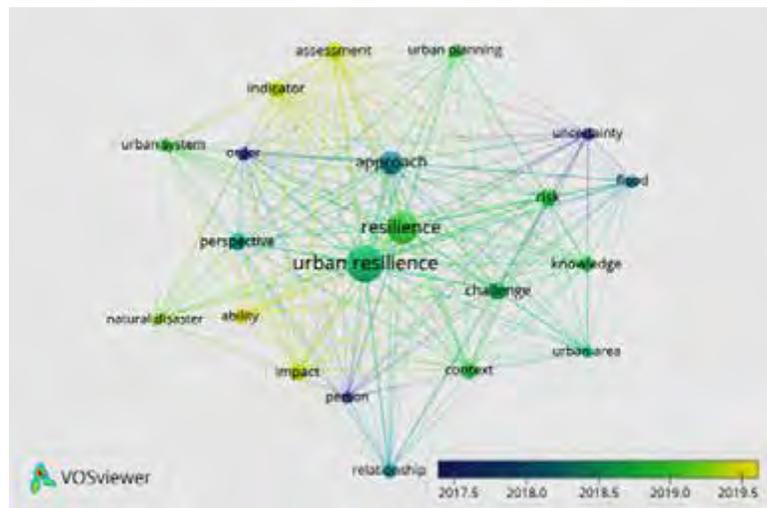


Figure 4: Conceptual network visualization: nodes & linkages of the keywords.

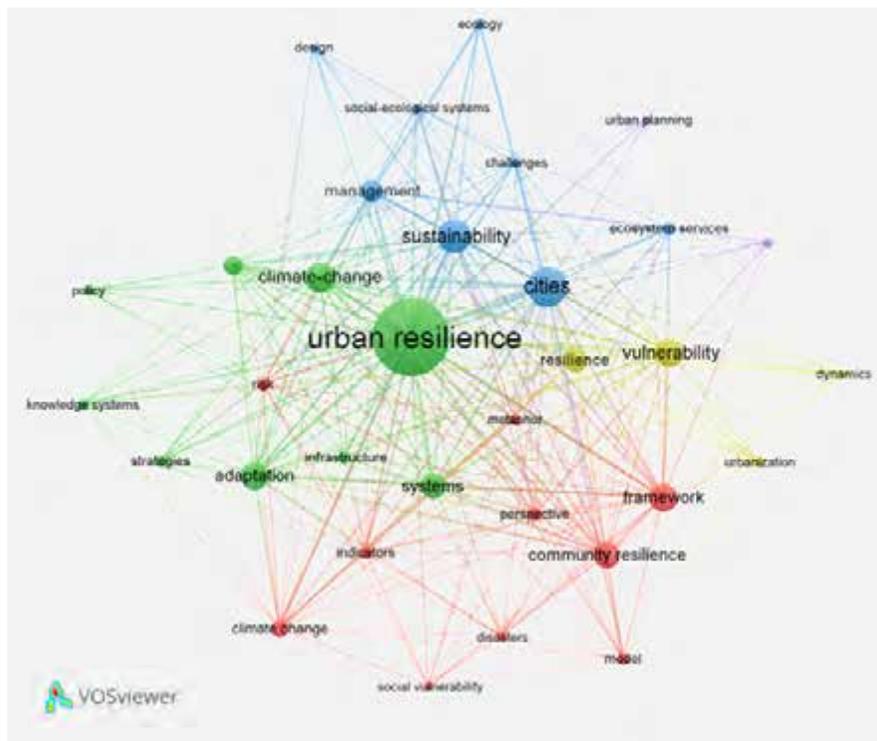


Figure 5. Full-text analysis: Co-occurrence network.

Significantly, through the full-text analysis, four clusters were identified in Figure 5. The green cluster is concerned with climate change policies, adaptation strategies, and urban resilience. The red cluster has a high degree of association with indicator-based assessment models and frameworks, indicating their utility as decision support tools. The violet and yellow color cluster represent the dynamics of urbanization and urban planning with resilience. The blue cluster discusses sustainability and its multifaceted relationship with urban planning, design, and management. The terms, including urban resilience, sustainability, vulnerability, cities, climate change, adaptation, community resilience, and management, have a higher occurrence and total link strength value, indicating that they have received additional attention and are strongly related to the other terms. Given the search string's inclusion of the terms 'urban resilience' and 'cities,' their higher values are somewhat expected. These terms are retained in the analysis due to the possibility of omitting related terms if they are excluded. As can be seen, these terms, along with others such as urban resilience, cities, sustainability, and climate change, are cluster-level terms with strong connections to other clusters and themes. The presence of terms such as 'indicator,' 'framework,' 'model,' 'systems,' 'design,' and 'policy' demonstrates that considerable effort has been expended developing assessment systems, including categories and indicator systems. At the same time, we find that factors such as social sustainability have the lowest level of linkage and co-occurrence, residing on the peripheries of urban resilience conversations, demonstrated in Fig. 5.

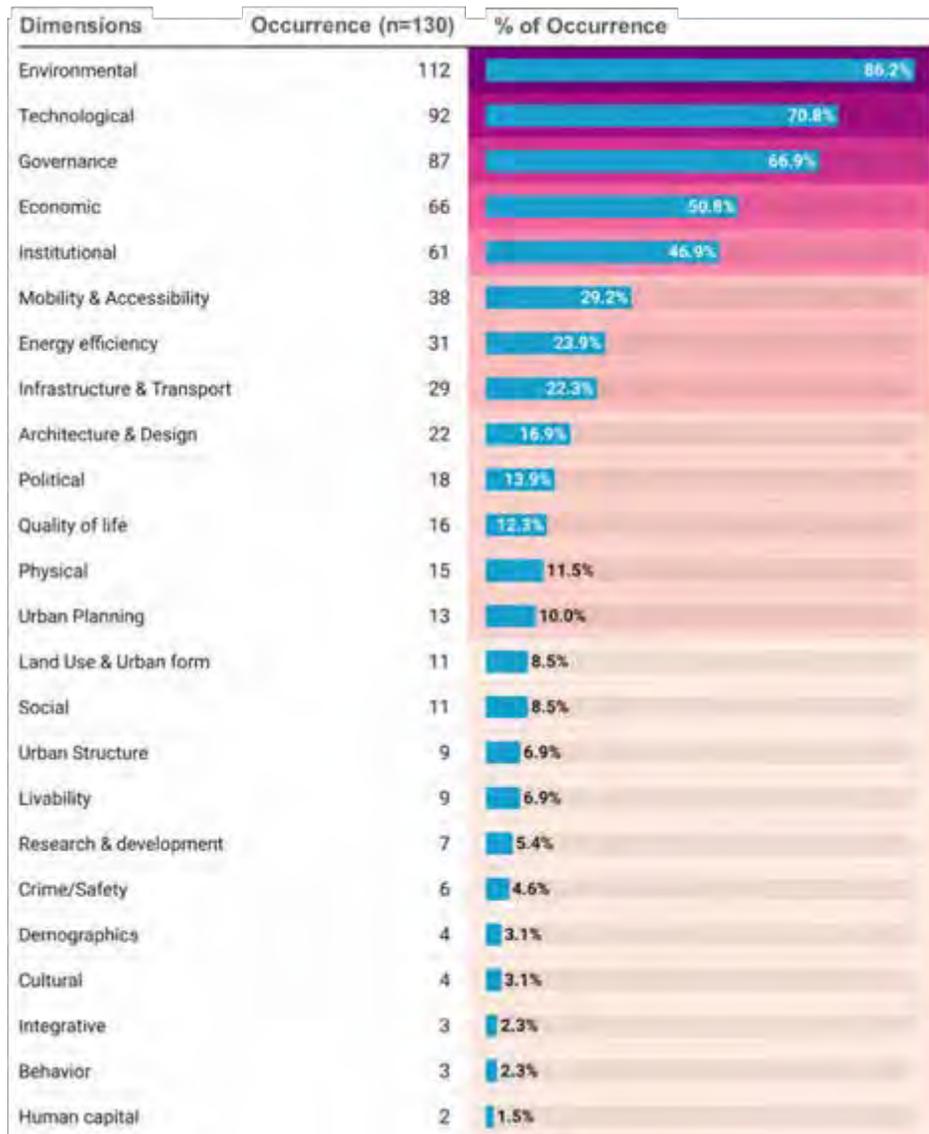


Figure 6. The dimensionality of resilience research.

We analyze the dimensionality of resilience research in Figure 6 measured by the frequency of publications that focus on various thematic dimensions (e.g., environment, economic, social, institutional) identified through the full-text analysis. We find four clusters: the first cluster is where the select thematic dimensions were emphasized in over 40% of the sample. The second set of factors in cluster two was mentioned in 20% to 40% of articles investigated. The fourth cluster attracted the lowest attention level at less than 10% of occurrence in 130 publications. The factors that received the most attention in the urban resilience literature (n=130) are environmental (112, 86.2%), technological (92, 70.8%), governance (87, 66.9%), economic (66, 50.8%), and institutional (61, 46.9%). Issues that attracted moderate interest levels are mobility (38, 29.2%), energy efficiency (31, 23.9%), infrastructure and transport (29, 22.3%), and architecture and design (22, 16.9%). Only 11 out of 130 (8.5%) articles studied focused on the social dimension. We find that cultural, behavioral, and human capital concerns were least highlighted in the urban resilience studies.

DISCUSSION

This study presents findings from a systematic review of urban resilience literature using topic modeling and Qualitative Content Analysis techniques. The first key finding is that urban resilience literature is predominantly published through outlets that fall under environmental domains (see Fig. 2), geosciences, ecology, climate, and green technologies. In contrast, social sciences and humanities journals are less frequently used as venues to disseminate resilience research. Our dimensionality analysis (see Fig. 6) provides further evidence that environmental, technological, governance and economic factors co-occur much frequently in the studied literature than issues relating to social, cultural individual behavior, human capital, and public health and safety. This trend is particularly concerning because social structure processes and community capital are critical pillars to urban resilience as much as green technologies, institutions, and infrastructure design [8, 10]. With limited emphasis and research on the social dimension of resilience, we leave our communities grossly underprepared to face extreme events and challenges. The experiences from the COVID-19 pandemic suggest that the role of social organization, behavioral changes, and community organizations to tackle disasters are critical alongside technological, scientific, and government responses [4, 6]. Our findings highlight the need for further research to bridge the knowledge gaps around socially inclusive urban resilience strategies.

The second important message from the analysis was that urban resilience studies are performed in a select few countries, whereas several global regions did not report any publications on this critical theme. Generally, the developed countries of Europe and North America produced the majority of research articles on resilience and showed well-developed researcher networks (see Fig. 3), whereas less-developed regions of Africa and Asia did not feature in such studies. This uneven global distribution of resilience papers appears to have skewed the literature focus on a select few themes while ignoring others. We found that keywords such as ‘indicator,’ ‘assessment,’ and ‘technology systems’ are heavily emphasized in the recent literature that is appropriate to the development context of the west. Contrarily, relevant Global South issues of informality, slums, and poverty never featured in these discourses. Weak knowledge systems in the developing and less-developed regions pose significant threats to global sustainability and disaster preparedness and recovery in an increasingly connected world.

The co-occurrence network based on the full-text analysis reveals the third valuable lesson: climate change, sustainability, and cities are at the core of urban resilience discourse, but issues of built environment design, social vulnerability, urban planning, and knowledge systems are at the edge. We found from the cluster analysis that significant research thinking was employed on building resilience frameworks, indicator systems, and sustainability management solutions. Factors of risk and adaptation also emerged at the heart of climate change discourse vis-à-vis urban resilience literature. Indeed, indicator-based risk and vulnerability assessments are critical to building resilience [11, 12]. But, to address a diversity of challenges associated with cities, urban resilience models need to better engage with the local dynamics, community structure, and policies evident from the analysis.

We propose that to achieve resilience and holistic sustainability, all dimensions, including socioeconomic, technological, environmental, economic, and institutional, must be addressed appropriately at all geographic levels. To this end, we present a novel toolkit for urban resilience assessment and modeling engaging with issues such as social equity, justice, public engagement, and individual behavioral change that were under-represented in the literature analyses. Our approach is to group the urban resilience indicators (derived from the reviewed papers) into four-level interventions, including individual-level, micro-level (area, site, and building), meso-level (community, sector/neighborhood), and macro-level (global, regional, city) design interventions. Interventions at the building level (e.g., design/redesign of interior spaces, building typology, layout, and efficiency of use) and at the city level (e.g., density, landscape connectivity, and transportation network) are significant (see Table I). Building on the current literature [18], we advocate for a holistic approach to environmental management with built environment design, including proper ventilation, air filtration, humidity regulation, and temperature control. Through urban planning, the structure and organization of cities, particularly the urban transportation system included in our model, have been shown to be critical in affecting social distancing rates and disease contagion rates [19].

Table I: Proposed resilience modeling scales and factors.

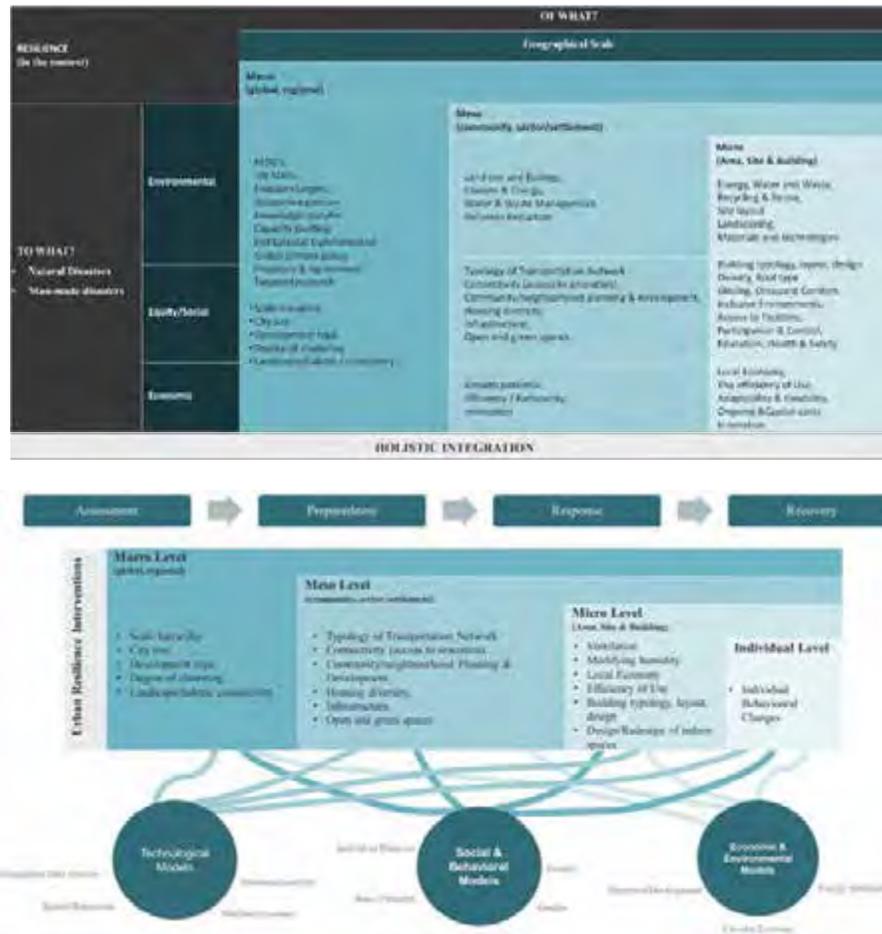


Figure 7. A Toolkit for Urban Resilience Assessment and Modelling.

Beyond focusing on different spatial scales and interventions, our toolkit for urban resilience assessment and modeling (Figure 7) integrates three models into one comprehensive framework. The literature review highlighted various technological models, including geographic data science, statistical, and computer models employed to assess urban resilience and design interventions. We also found various literature focusing on environmental and economic models around energy sustainability, circular economy, and climate change leading to adaptation strategies, ecosystem services planning, and response mechanisms. We extend these modeling frameworks to include social and behavioral dimensions, including poverty, gender, race/ethnicity, and individual behavior feeding to the hierarchical assessment at various scales, preparedness to emergencies, and response and recovery from any crisis. While this toolkit provides a general guideline, we encourage the extension and modification of this model based on local context and needs.

CONCLUSION

Urban resilience is critical for ensuring the natural and built environment quality and population well-being and for ensuring the sustainability of cities that are the engines of economic growth and opportunity. The ongoing COVID-19 pandemic highlights the need for our communities to be responsive to changing realities and needs. This article presented a multidisciplinary systematic review of urban resilience literature and identified critical gaps in the existing resilience studies and frameworks. This review initially found 1821 papers from Web of Science and 3272 papers from Scopus, of which 130 articles were included and analyzed that use various urban resilience keywords, concepts, and models to advance knowledge of resiliency planning. Several analyses using VOSviewer were presented, including thematic dimensions of urban resilience literature, publication of resilience articles and citations by country, and the cluster co-occurrence network through full-text analysis. Our research reveals the complex web of urban resilience research, key areas commonly emphasized in the literature, and the issues often disregarded in this debate, offering essential lessons.

Consequently, we propose an urban resilience assessment and modeling toolkit for scientists, planners, designers, and public authorities by answering the research questions raised at the beginning of our study. This toolkit can help combine strategies, models, and metrics to influence design implementations and evaluate the effects of various resilience interventions on cities, regions, and other areas of interest. The toolkit may also complement models that help in assessing resilience indicators related to environmental, economic, and social sustainability at various geographic scales. Appropriate comprehension of the factors identified in this study is necessary for ensuring social equity in urban resilience planning for sustainable development. The limitation of this research is that we primarily relied on WoS and Scopus for the literature search. Future research might focus on improved systematic review management to include a broad selection of databases. Emerging subscription-based platforms such as ‘covidence’ and ‘EPPI-Reviewer’ can be used to that end to expand the scope of the online literature search to include non-traditional documents, reports, and other forms of publications that are not listed under Scopus or WoS. A collection of such research can help compare and validate the findings reported in this study.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the use of Google, Web of Science, and Scopus databases for the collection of the literature data. We also disclose the use of VOSviewer software tool for constructing and visualizing the bibliometric networks.

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THE POST-COVID19 URBAN ENVIRONMENT: THE EFFECTS OF PANDEMIC CONTAINMENT MEASURES ON THE DEMAND FOR URBAN GREEN SPACES IN ITALY

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ABSTRACT

Countries around the world have implemented a variety of stringent policies to fight the SARS-Cov2 pandemic. These measures have been introduced to reduce the spread of the virus by requiring physical distance between people, but most likely they have also changed how people use urban areas. Some studies have already demonstrated how “spending time outdoors” was particularly missed during the COVID-19 isolation, and how urban green spaces were critical for providing places of solace and relaxation. The purpose of this research is to examine how the pandemic and containment measures affected mobility in Italy, with a focus on urban green spaces.

Google COVID-19 Community Mobility Reports, which provide a regularly updated dataset showing how people’s movements have changed throughout the pandemic, provide an excellent opportunity to investigate how people’s mobility and frequentation of urban environments has changed. Every day, the reports provide measures of visitor numbers to specific categories of locations (e.g., grocery stores, parks, train stations, workplaces, relatives residents, retail, and recreation), comparing this change to the baseline before the pandemic outbreak. The present study shows that mobility to parks and green spaces has increased significantly between 2020 and 2021, and in the absence of restrictions, visitors to parks grew mostly in the provinces with the poorest air quality.

KEYWORDS

SARS-Cov2 Pandemic, Mobility, Urban Green, Lockdown, Air Quality

INTRODUCTION

Starting from the end of the 2019, the whole world has been struck by the diffusion of an unknown virus, called later “2019 novel coronavirus” (2019-nCoV). The initial outbreak was reported in the city of Wuhan, China, then spreading in Europe and in the rest of the world [1]. Coronavirus is an RNA virus and belongs to the *Orthocoronavirinae* subfamily, with the characteristic “crown-like” spikes on their surface [2], and the typical symptoms are fever, dry cough, and fatigue [3]. On the 13th of March 2020, Europe was declared the epicenter of 2019-nCoV pandemic [4]. The first case of COVID-19 in Europe was reported in France on the 24th of January, followed by Germany and Finland few days later [5]. In order to mitigate the COVID-19 outbreak, many European countries implemented travel restrictions, closed borders, and prohibited non-citizens from entry [6], also because of the critical role of mobility during the early stages of a pandemic [7]. A study [5] assessed that the highest value of initial community spread in whole Europe occurred in Italy, also because of the strongest network connections to the rest of Europe, especially mobility of air passenger travel, known as a strong contributor on diffusion of the pandemic [8].

On the 23rd and 24th of February 2020, the Italian National Health Service reported two hot spots of COVID-19 cases in two geographical areas of northern-Italy, respectively in Lombardy and in Veneto [9]. For this reason, the Italian government established two “quarantine” areas, where stringent measures to contain the epidemic were introduced immediately starting from the 24th of February. These measures included imposing strong restrictions on people mobility and the temporary closure of schools, shops, and industrial activities [10].

On the 8th of March, the Italian government extended these restriction measures from the hot spots to all the Lombardy region, and eventually to the whole country on the 11th of March 2020. From this date, Italy was in a “lockdown” phase till the 3rd of May 2020, when loosening of restrictions were allowed by the epidemiological data [11].

Despite media portrayals of people ignoring the restrictions during the lockdown period, mobility data clearly show that since March, the range of movement dropped dramatically to a nearly physiological level, such as supplies, health workers, and necessary activities. [9].

Starting from the 4th of May, people could move to parks, shops, and bathing facilities, within the same region and after the 14th of June 2020, all the restrictions were removed for the summer season, until approximately to the end of September, when some restrictions were restored due to the increasing number of the infections.

Afterwards, a new epidemiological monitoring system, called “zone system”, was introduced starting from the 6th of November [12] and still used. At the beginning, the zone system consisted of three different zones (red, orange, and yellow) and from the 16th of January 2021 an additional zone (white) (**Table I**), depending on the net reproduction number (R_t) [13]. The “red zone” was the one corresponding to the more severe restrictions, not too far from the previous lockdown phase, while the “orange zone” allowed mobility only within the same town. Finally, the “yellow zone” and the “white zone” admitted a loosening of the restrictions, in compliance with health regulations.

Some studies outlined that considering the number of COVID-19 deaths for , the most affected areas were found in the Po Valley, a region that is also characterized by a high particulate matter concentrations [14]. The correlation between the epidemic curve and environmental pollution has been also investigated analyzing in particular the Lombardy Region, [15] concluding that the probability of the viral particles to be scavenged from atmosphere aerosol particles in outdoor air, with the exception of crowded areas, was negligible, even in a worst case scenario and assuming a number of infects up to 25% of local population.

Excluding the environmental factors as involved in the major diffusion, a strong contributor to the global spreading of COVID-19 was identified in citizens mobility on the territory [16].

In the time period 1st of February – 30th of September 2020, a 2-week lag positive association between the mobility flow peak and the net reproduction number (R_t) peak was estimated, strong in March and April, and weaker but still significant in June, both at regional and provincial level in Italy [17].

Considering mobility of students to schools, a strong correlation between a high rate of contagion in school and a high contagion rate at the provincial level was identified, in the Lombardy Region, for the reference period 14th of September – 30th of October 2020 [18], and it is interesting that the correlation is not found instead by considering at the population density.

The purpose of this paper is to show how mobility in Italy was affected by COVID-19 restrictions and no-restrictions, with a special focus on the mobility towards urban green areas and parks. Multivariate statistical analysis and clustering methods were applied in order to highlight mobility pattern variations during the two investigated years, in reason of the restrictions in force.

Table I: Zone system generalities and characteristics.

| | White zone | Yellow zone | Orange zone | Red zone |
|--------------|--|--|---|--|
| R_t number | $R_t < 0.5$ (< 1 *) | $R_t = 0.5 \div 1$ ($1 \div 1.25$ *) | $R_t = 1 \div 1.25$ ($1.25 \div 1.5$ *) | $R_t > 1.25$ (> 1.5 *) |
| Restrictions | <ul style="list-style-type: none"> Obligation to wear a mask Physical distancing Local red zones Suspension of activities more at risk Closed museums during weekends (until the 5th of March 2021) | <ul style="list-style-type: none"> Curfew (abolished on the 21st of June 2021) Catering services close at 6.00 pm (outdoors at 10.00 pm from the 26th of April to the 31st of May 2021) Shopping centers closed on weekends Distant learning for high schools Closure of cinemas and theaters (until the 26th of March 2021) Closure of sportcenters and clubs Ban of conferences, festivals, and fairs Closed museums during weekends (till 5th of March 2021) | <ul style="list-style-type: none"> Curfew Prohibition to move outside the Municipality Closure of catering services Closure of cinemas, theaters, and museums Distant learning for high schools Shopping centers closed on weekends Closure of sports centers and clubs Closure of betting rooms Ban of conferences, congresses, and fairs | <ul style="list-style-type: none"> Curfew Unjustified traffic ban Closure of catering services Closure of shops and retail markets Distant learning at school from the second grade Closure of hairdressers and beauty centers (from the 6th of March 2021) Closure of cinemas, theaters, and museums Closure of sports centers and clubs Ban of conferences, congresses, and fairs |

* : R_t number before 16th January 2021.

MATERIALS AND METHODS

Mobility dataset

Mobility information were extracted from the COVID-19 Community Mobility Reports published by Google. This dataset shows how visits to workplaces, parks or groceries and markets changed during the pandemic, and how visits and length of stay at different places changed regarding to a baseline. Mobility is subdivided in six categories, which define different destinations (Table II). As baseline the median value, for the corresponding weekday, of the the 5-week period Jan 3–Feb 6, 2020 has been assumed. So mobility changes for each day are evaluated with respect to this baseline for that weekday [19].

Table II: Mobility categories considered in COVID-19 Community Mobility Reports set by Google.

| Destination | Description |
|---------------------|---|
| Grocery & pharmacy | Mobility to places like grocery markets, food warehouses, farmers markets, specialty food shops, drug stores, and pharmacies. |
| Parks | Mobility trends for places like local parks, national parks, public beaches, marinas, dog parks, plazas, and public gardens. |
| Transit stations | Mobility trends for places like public transport hubs such as subway, bus, and train stations. |
| Retail & recreation | Mobility trends for places like restaurants, cafes, shopping centers, theme parks, museums, libraries, and movie theaters. |
| Residential | Mobility trends for places of residence. |
| Workplaces | Mobility trends for places of work. |

Air quality data

Air quality data have been retrieved from regional environmental protection agencies' (ARPAs). A total of 107 meteorological stations, which collected data on temperature, humidity, and wind speed, were also considered. Only urban stations were considered and the median concentration value for the three parameters was assumed for the whole province.

Daily median values of PM₁₀, NO₂, CO, O₃, and SO₂ were also examined to provide an index of air quality. It was decided to use the European Environment Agency's air quality index (European Air Quality Index, EAQI) (Eq.1).

$$\text{EAQI} = \text{Max} \left(\frac{\text{PM}_{10}}{50}, \frac{\text{NO}_2}{90}, \frac{\text{CO}}{10000}, \frac{\text{O}_3}{100}, \frac{\text{SO}_2}{125} \right) * 50 \quad (\text{Eq.1})$$

Air quality classes were defined based on pollutants' values considering the EAQI percentiles. Three air quality classes were evaluated, representing low, moderate and high air quality.

Covid-19 Incidence data

In order to evaluate the risk associated to the exposure of the virus in the Italian territory, an incidence index was calculated. Data about the total daily cases were found in the GitHub portal of the Italian Civil Protection Organization (<https://github.com/pcm-dpc/COVID-19>), as daily provincial new cases. The evaluation of the population incidence index was the following (Eq.2).

$$\text{Incidence} = \frac{\text{Total new daily cases} * 100000}{\text{Provincial total population}} \quad (\text{Eq.2})$$

Statistical tools and models

All the statistical computations were performed using IBM SPSS Statistics Software (version 27). Factor Analysis (FA), Principal Component Analysis (PCA), and Cluster Analysis (CA) were used to assess possible correlations between variables, and similarities between single observations [20], [21]. Factor Analysis was obtained through a preliminary Principal Component Analysis (PCA), a statistical tool able to define new uncorrelated variables that are linear functions of those in the original dataset. In fact, PCA seeks a linear combination of input variables that yields the maximum variance of the bivariate correlation matrix. Following that, PCA extracts the maximum variance of the remaining variance using a second orthogonal linear combination to the first, and so on. In a specific orthogonal dimension, PCs represent all the linear combinations of the original variables weighted by their contribution to explaining the variance. Through a Varimax rotation it was possible to maximize the sum of the variance of the squared correlations between variables and Principal Components. A set of Factor were extracted, based on the correlation matrix between mobility variables [22]. The number of Factors to be retained was determined using a fixed number extraction rather than the "eigenvalue greater than 1" criterion (i.e., all Factors that explained less than the variance of one of the original variables were discarded). In fact, the third Factor had an eigenvalue that was slightly less than 1. Following the PCA/FA, a cluster analysis (CA) was applied to the extracted vari-factors. The clusters were identified using the K-means method, an unsupervised clustering technique capable of separating observations based on mutual variability. By entering the previously extracted factor scores with PCA / FA as input, significant mobility patterns were identified. The core of the statistical analysis was carried out using generalized linear models. These are extremely powerful tools for highlighting the influence of fixed factors, or covariates, on the dependent variable, according to a multivariate regression analysis. These models describe the pattern of interactions between predictor and response variables and offer quantitative measures of the strength of the associations. Because GLMs evaluate the interactions between dependent and independent variables, the residuals of the dependent variable resulting from the regression can be extracted from the model to remove any bias or disturbances within the data using a regression analysis. These residuals were evaluated calculating the ratio of the difference between the single observed and the simulated sample, and its standard deviation. The residuals were used in this analysis to investigate mobility toward parks, removing any seasonality bias that might have affected the estimates.

RESULTS

The dimensionality of the mobility categories was reduced by using a Factor analysis (FA). Three Principal Components were found using the Principal Component Analysis (PCA) approach, accounting for 94 % of the total variance. Principal components were converted into three Factors using the Varimax Rotation (**Table III**).

*Table III: factor scores of each mobility category after the Varimax rotation.
The most important factor scores (higher than 0.6) are written in bold. Only scores higher than 0.50 are displayed.*

| Rotated component matrix ^a | | | |
|--|---------------|--------------|--------------|
| Variables (percent change from baseline mean) | Factor loads | | |
| | 1 | 2 | 3 |
| retail and recreation | 0.505 | 0.616 | 0.551 |
| grocery and pharmacy | | | 0.883 |
| parks | | 0.924 | |
| transit stations | 0.544 | 0.699 | |
| workplaces | 0.917 | | |
| residential | -0.784 | | |
| Eigenvalue | 4.627 | 0.613 | 0.405 |
| % of variance | 77.112 | 10.218 | 6.745 |
| % cumulative variance | 77.112 | 87.330 | 94.075 |
| Extraction method: Principal component analysis | | | |
| Rotation method: Varimax with Kaiser normalization | | | |
| a. Convergence in 5 iterations. | | | |

The first factor, which reflected mobility toward workplaces and inversely towards residences, explained more than 77 percent of the variance. The second factor accounted for movement toward retail, recreation, and green spaces (urban and suburban), and explained more than 10% of the total variance. Finally, the third factor, which reflected mobility for supplies, explained over 7% of the total variance. It was possible to assess that the relationship with the relevant Factor was strict for some place categories (for example, workplaces and residential areas in Factor 1), while for others, the relationship was not as strict as for the previous. In fact, retail and recreation mobility is approximately evenly distributed among all three Factors, and this is also true for the transit stations category. In order to better explain the mobility trends found by PCA/FA, a cluster analysis was performed, with the K-means approach. After some trials a four-cluster solution was chosen. The four cluster centroids created in the first iteration slot were used as the initial position of the cluster centroids in the second iteration slot to enhance algorithm convergence.

The first cluster's factor loads were lower than the overall mean (**Figure 1**): in fact, 35% of cases in this cluster referred to the lockdown period, and 23% of cases referred to the red zone, justifying the negative mean value in the three mobility factors. The second, less populous cluster, contained almost completely mobility values referring to periods when no mobility restrictions were imposed. The third cluster had around 50% of the cases related to periods of no restrictions, with the majority of the remaining cases dating back to the lockdown period (13%), orange zone (14%), and yellow zone (13%). Cluster 4 was the most populous and reflected the most diffused pattern of the three factors, with numerous cases dating back to the yellow zone (30%), orange zone (19%), and no restrictions period (43%).

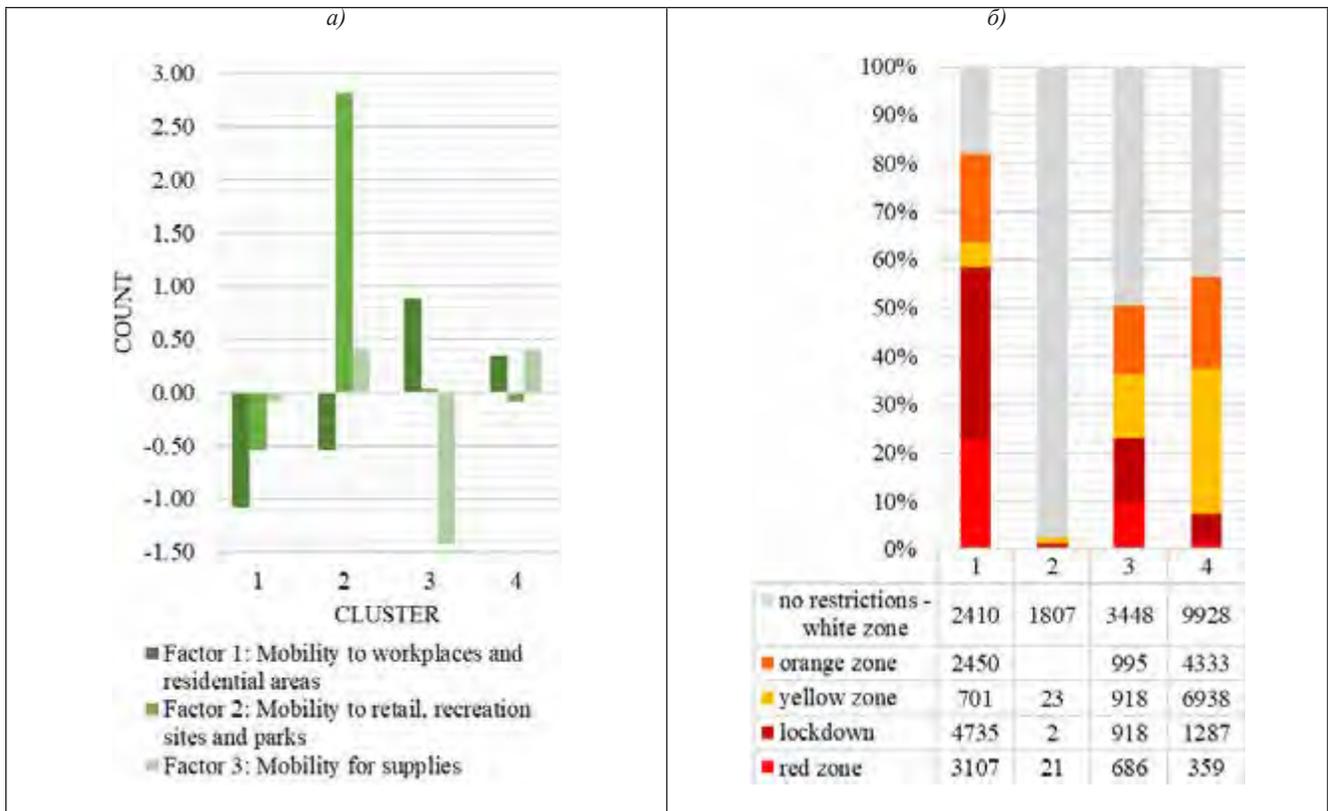


Figure 1: the composition of observations inside each cluster.

a) factor scores inside the four clusters for the three factors of mobility. b) number of zones cases inside each cluster.

Cluster 2, which was mostly made up of unrestricted mobility values, could indicate Italian mobility free of government constraints. Clusters 1, 3, and 4 showed no discernible changes in regional trends.

An analysis by single region was implemented to better explain the dynamics in mobility patterns across Italian territory, as well as the impact of government limitations (Figure 2). While clusters 1, 3, and 4 had comparable regional compositions, the cases in the second cluster had a different spatial distribution. Lombardy, Piemonte, Emilia-Romagna, and Veneto were the most populous regions in clusters 1–3, while Abruzzo, Calabria, Marche, Liguria, Puglia, Sardegna, Toscana, Sicilia, and the Autonomous Province of Trento were the most populous in cluster 2. The existence of several parks (as defined by Google in the datasets) and tourism outdoor activities contributed to group these regions.

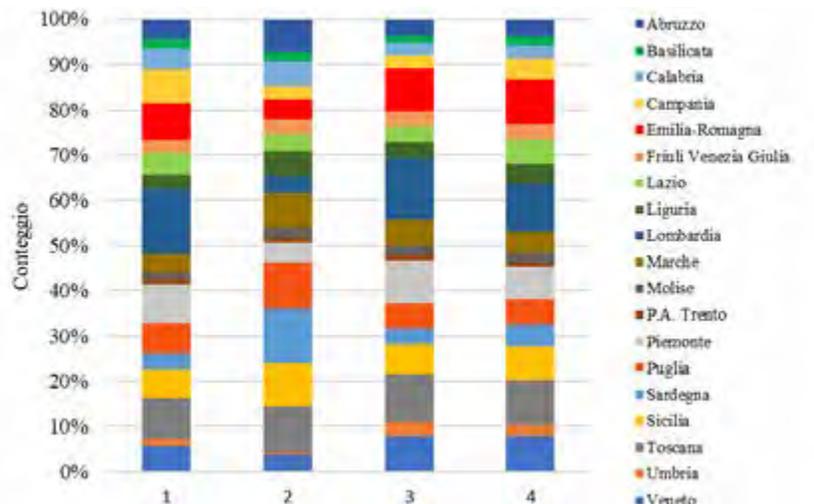


Figure 2: the regional composition inside each cluster.

These areas have been designated as “touristic regions” due to the existence of beaches and parks, as well as constant mobility during the summer season. Mobility towards parks was evaluated as a dependent variable in a GLM (Table IV) to reveal any influence owing to seasonality and region typology (“touristic regions” vs. “non-touristic regions”). The month and the boolean variable that separated touristic from non-touristic regions were included as fixed factors, whereas meteorological data (such as temperature, humidity, and wind speed) were considered as covariates. Every fixed factor and covariates had a considerable impact on mobility to parks. The month was the most important factor in terms of F, while among the covariates, mobility was primarily influenced by temperature. Given the complexity of the dataset and the geography examined, which encompassed an entire country with significant territorial and climatic variances, this model performed satisfactorily.

Table IV: GLMs between subjects effects. The “sum of squares” column displays the sums of squares for variables variance. The “mean square” column displays the sum of the squares divided by the number of degrees of freedom (“df” column). Columns “F” and “Sig.” are the most crucial, as they correspond to the F-statistic and the p-value of the single variable. The F statistic is determined by dividing the variance between groups by the variance within groups. The p-value is compared to an alpha level of 0.05; the test has the condition of equality between the means of the individual groups as a null hypothesis.

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|--|----------------------------|-------|-------------|----------|--------|
| Correct model | 107119605,850 ^a | 26 | 4119984.840 | 1225.802 | < 0.05 |
| Intercept | 497391.697 | 1 | 497391.697 | 147.987 | < 0.05 |
| Temperature [°C] | 889592.751 | 1 | 889592.751 | 264.677 | < 0.05 |
| Humidity [%] | 631486.693 | 1 | 631486.693 | 187.884 | < 0.05 |
| Wind speed [km/h] | 749941.813 | 1 | 749941.813 | 223.127 | < 0.05 |
| Month | 30775101.691 | 11 | 2797736.517 | 832.399 | < 0.05 |
| Regional classification (touristic vs. non-touristic) | 1758573.118 | 1 | 1758573.118 | 523.221 | < 0.05 |
| Month * regional classification | 6869070.951 | 11 | 624460.996 | 185.793 | < 0.05 |
| Error | 111402078.044 | 33145 | 3361.052 | | |
| Total | 228477462.250 | 33172 | | | |
| Total correct | 218521683.893 | 33171 | | | |

$$^a \cdot R^2 = 0.490 \text{ (Adj. } R^2 = 0.490)$$

With the start of the summer season, mobility became more intense, with a significant peak in August (Figure 3). However, due to anti-covid measures, there was a significant decrease in visitors to green areas in April.

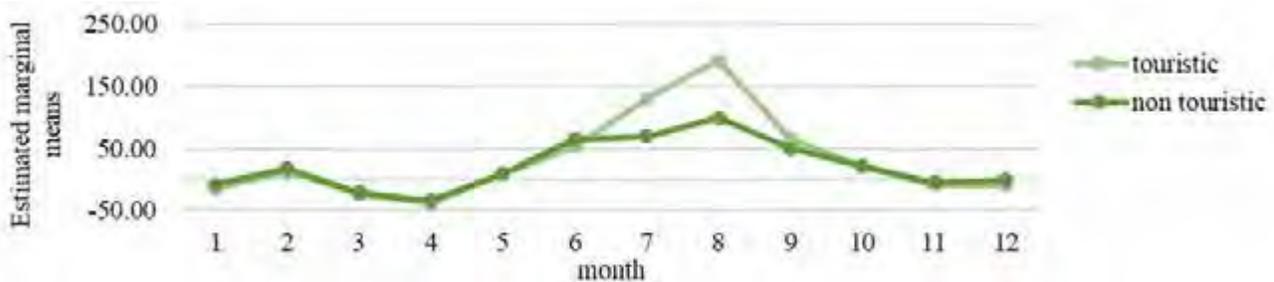


Figure 3: Park percent change marginal means estimated by GLM for touristic and not touristic regions.

The bias owing to the summer season is also visible in non-touristic places, indicating a larger desire to visit green areas. Because Google evaluates mobility values using a winter period as a baseline, this may introduce a bias in the analysis, as mobility to parks during the winter season is noticeably lower than during the warmer months of the year. To remove the influence of seasonality from the analysis, residual estimates of the model were assessed in order to establish standardized mobility values and remove the influence of seasonality. The 2021 residuals were compared to the 2020 residuals (Figure 4). The year 2021 was mostly marked by light anti-covid measures, which allowed people to go to parks and urban green spaces.



Figure 4: comparison of residuals of parks percent change from baseline mean in 2020 and 2021.

Another factor considered was the incidence of contagion. The perception of the risk of getting the virus has clearly reduced people’s travels. To demonstrate this effect, the month of May 2021 was considered, which included mobility restrictions but enabled people to go to parks (the so-called “yellow zone,” as well as days with no restrictions). The model’s dependent variable were the residuals generated by the preceding model, which represent the mobility to parks independently from the seasonality effects (Table V). In this model the province and the three air quality classes evaluated using EAQI were chosen as fixed factors, and the province incidence was chosen as a covariate.

Table V: GLMs between subjects effects. The dependent variable is the residuals resulting from the previous GLM. The p-value is compared to an alpha level of 0.05; the test has the condition of equality between the means of the individual groups as a null hypothesis.

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|-------------------------|--------------------------|------|-------------|---------|--------|
| Corrected Model | 1426430,434 ^a | 123 | 11596.995 | 15.466 | < 0.05 |
| Intercept | 376889.211 | 1 | 376889.211 | 502.619 | < 0.05 |
| Provincial Incidence | 51034.694 | 1 | 51034.694 | 68.060 | < 0.05 |
| EAQI classes | 49620.990 | 2 | 24810.495 | 33.087 | < 0.05 |
| Province | 768065.222 | 53 | 14491.797 | 19.326 | < 0.05 |
| EAQI classes * Province | 98887.974 | 67 | 1475.940 | 1.968 | < 0.05 |
| Error | 1051291.722 | 1402 | 749.851 | | |
| Total | 4261344.008 | 1526 | | | |
| Corrected Total | 2477722.156 | 1525 | | | |

^a. $R = 0.576$ ($Adj. R^2 = 0.538$)

GLM (R2=58%) statistics showed that all fixed factors and covariates were significant. The provincial incidence was the most impactful determinant on park mobility in terms of F. Mobility to parks was greatly enhanced in areas with high EAQI levels (and therefore poor air quality) (Figure 5). This could be an indication of the need for residents living in polluted places to seek relief in green areas.

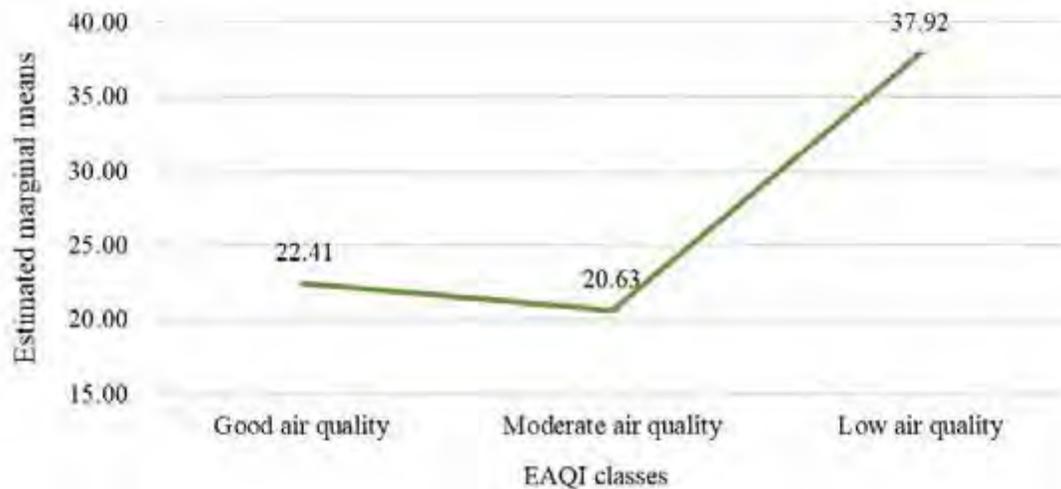


Figure 5: Estimated marginal means of parks percent change residuals

DISCUSSION

The application of multivariate analysis approaches has been shown to be essential for deciphering the dynamics captured by covid-19 epidemics. Some previous research revealed that the most densely populated areas are the most vulnerable to the contagion, and that the popularity of green spaces has grown as the pandemic has progressed [23] [25] [26]. Unlike prior research that considered only mobility or contagion patterns [24] [27], this study investigated the influence of combining more elements on the frequency of visits to green spaces in Italy, such as air quality and the virus diffusion. In addition to this study, others have identified an increase in the utilization of green places as a result of the need to relieve stress [28]. It was possible to recognize that the mobility categories could be summarized into three factors: mobility to green spaces was discovered to be associated with mobility to other areas for recreational purposes as well as to the main local public transportation arteries. With the cluster analysis, a peak was identified in the mobility to parks in periods when the season and restrictions allowed it, but an increase was also highlighted in periods of restrictions (orange and yellow zones). The only thing that discouraged people from visiting the parks was the lockdown, which effectively stopped all movements. With the first GLM it was possible to appreciate that the gap between one year and the next in residual trends is large. Almost all regions were subject to lockdown-like restrictions in February 2021. (the so-called “red zone”). As a result, fewer people visited green spaces in February 2020 than in February 2021. The tendency began to reverse in March. People were unable to attend parks in 2020 due to lockdown, which is clearly visible in **Figure 4**. Restrictions on leisure facilities were ignored in 2021, allowing people to participate in outdoor sports and activities. As limitations eased in 2021, there was an increase in the number of people visiting green areas. This concession resulted in significantly more mobility than the average, with a substantial peak in the month of April. In 2021, June was the first month without restrictions in Italy. This has resulted in an increase in mobility to open areas and green areas. The GLM applied on the residuals of the first GLM explains the dynamics between park attendance, incidence of the contagion and air quality. It should be remarked that it was difficult to assess air quality since where data were available, some information was missing (e.g. there was no indication of the types of air quality monitoring stations i.e. urban, rural, or industrial), and, in many regions, data availability was very poor. Given the heterogeneity of the information on the air pollutants present, it was decided to use a quality index to support data analysis, then subdivided in three classes based on data percentiles. The impact of contagion incidence and air quality was significant. This result, however, must be interpreted: in Lombardy, for example, which was the initial cradle of the virus’s exposure, there was a significant incidence in the population; moreover, it is a region that almost entirely falls within one of Europe’s most polluted areas, the Po Valley. Despite these aggravating factors, it has been demonstrated that in a similar territory parks visits were not discouraged by social and environmental factors, and thus the resident population in those areas considered to visit the available green areas an important and healthy activity. Despite the public’s concern about the pandemic, green spaces have proven to be a worthwhile destination for getting out of the house and relieving stress.

CONCLUSIONS

Data analysis revealed a trend toward enhanced park attendance during the pandemic. The analysis of Google mobility data has shown a considerable variation in mobility toward parks between touristic and non-touristic locations. The mobility categories have been arranged based on their variability. As a result, mobility to parks was found to be related to mobility to recreational areas and transit stations. In relation to the limits imposed to contain the Covid-19 infection, it can be stated that the lockdown has severely restricted all types of movement, but during periods of lower restrictions, mobility to parks has increased.

A generalized linear model was used to compare 2020 and 2021 (when there were no government restrictions in both years). Model residuals were used to examine mobility by removing the seasonal bias present in Google mobility data and examining the impact of government restrictions and air quality. As a result, in the lack of constraints, visitors to parks grew mostly in the provinces with the poorest air quality. Despite the heterogeneity of the data and the analyzed region, it is reasonable to conclude that the visits to the park were influenced by environmental conditions, air quality, and the incidence of infection.

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MOBILISING DIGITAL ENABLERS FOR CITIZEN ENGAGEMENT IN URBAN REGENERATION

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ABSTRACT

The smart city has come to signify the application of digitalisation in urban development. The strong attention and resources devoted to developing smart cities are, however, paralleled by hurdles and setbacks. Issues arise due to, e.g., the dominating influence of narrow expertise and/or vested interests. A voluminous literature points to challenges in meeting with citizens' needs, and/or lacking requirements for achieving relevance in addressing fundamental challenges in urban development, such as fragmentation, polarisation, and under-representation by disadvantaged groups. During the recent on-set of COVID-19, increased benefits of digital communication blend with new concerns and drawbacks, such as fatigue, risk of conformity, and mismatch between technical requirements and user skills.

Such issues inspire other models for urban development, including eco-cities and inclusive cities, and place focus on avenues for spurring broad-based benefits, such as Nature-Based Solutions (NBS). Drawing on the H2020 project URBiNAT, this paper revisits the rationale for applying 'digital enablers' to both deepen and broadening citizen participation, identifying four critical building blocks: purpose, method, content, and tools. Their practical application may benefit from leveraging constructive "Communities-of-Interest" pursued in parallel across interlinked cities, operating in sync with awareness creation and measures on the demand side, while minimising the presence of downsides. It concludes with recommendations of relevance to cities as well as stakeholders and research, linked to observations of next stage operationalisation in support of continued learning processes and practical lessons of high general validity.

KEYWORDS

INTRODUCTION

As Information and Communications Technology (ICT) has come to permeate most strands of economic and social life over the past half-century, the concept of digitalisation has been applied to refer to the ubiquitous, seamless conversion of data into a digital format. The upgrading of business models, organisational change and scope for innovation have been the epicentre for much of the associated literature. Extending from there, however, today digitalisation refers to a far-reaching systemic societal transformation, accompanying the utilisation of ever-increasing amounts of digitised data, turned into intelligence and actionable knowledge (cf. Castells, 2010).

The scope for new initiative and innovative activity emerging with digitalisation is paramount in urban development. The key flagship for this movement has been the “smart city” concept. Numerous cities adopted smart city agendas which have been described and examined by a wealth of research studies. Much attention has been devoted to sectoral approaches and specific technologies (Hölscher et al., 2019). Business development and innovations ensuring market-friendly and commercially viable outputs similarly feature regularly. Gradually, however, questions have arisen regarding focus and orientation (Hollands, 2008). Attention has been drawn to downsides, e.g., excessive focus on high-tech and favouring of vested interests. Some point to tendencies of breeding a culture of unheralded acceptance of influences by narrow expertise and/or vested interests (Swyngedouw 2007; Vanolo, 2014).

The interlinkages between economic, social and environmental aspects have gained traction (Souter and McLean, 2012; Digital Europe, 2019). Contemporary urban development keeps struggling with institutional, political, and administrative impediments, while battling a host of inter-related challenges spanning, e.g., resource waste, carbon footprints, fragmentation, polarisation, and exclusion (Filion et al., (2015). In this context, other connotations are gaining ground, e.g., Eco-cities, or Green and Inclusive cities, signalling shifting priorities but also needs of communication. Human behaviours as well as realising well-being and sustainability have emerged as a central theme rather than an after-thought in urban strategy formulation.

Properly managed, smart devices widen the scope for engaging citizens on outstanding issues as well as for working out, implementing, and monitoring solutions (Brabham, 2009; Gabrys, 2014; Brorström et al., 2018). With the on-set of COVID-19 in the last few years, use of digital communication became critical as a means for disseminating information to citizens, while also a source of relief and breeding ground for social initiatives. At the same time, previously well-known issues, e.g., risk of fatigue, conformity, and mismatch between technical requirements and user skills, lingered (Picazo-Vela et al., 2012; Gordon and Mihailidis, 2016; Andersson et al., 2021a).

The idea that improved access to ICT for disadvantaged groups by itself serves as an equalizer, fell flat many years ago (Azari and Pick, 2005), reflecting the wider debacle on the subject of *digital divide*. ICT has clearly alleviated many social disparities, associated with affordability, safety, and lack of access to service (Rice and Katz, 2003; Castells et al., 2007), while other gaps - in knowledge opportunity and income - have widened (OECD, 2001; Joss, 2018).

Whether labelled smart cities, eco-cities, or in other ways, urban development remains relatively weakly informed of the means for pursuing urban regeneration through broadened participation (Shiple and Utz, 2012). On this basis, the present paper contributes to the literature by taking a closer look at the requirements for putting digitalisation to work in urban regeneration through support of co-creation, notably related to NBS and Healthy Corridors, while staying clear of the downsides. In this, we draw on the ongoing work of URBiNAT, a Horizon 2020 project that engages seven cities in the EU, as well as some outside the EU, aiming for structured experimentation and learning processes of practical relevance to governance mechanisms for more inclusive and prosperous city development.

The paper is structured with the ensuing section providing a brief introduction to the definitions and key features of the smart city agenda. This is followed by observations what is actually new, with emphasis placed on the scope for deepened as well as broadened citizen participation. Examining digital enablers as a means in this context, the paper reviews four main building blocks, links to Communities of Interest, awareness creation and measures on the demand side. It is further underlined that the implementation of digital enablers requires consideration to limiting the downsides. The paper ends with recommendations and conclusions.

THE SMART CITY AGENDA

A vast literature considers the means of leveraging the value of digitized data and processes through business model development and organisational change. The scope and impacts of digitalisation are highly diverse, however, as is discernible at varying levels of aggregation, spanning individuals, communities, cities, regions, national states, and so on. Yet, what role ICT plays is complex and the ultimate significance in terms of productivity, quality of life and societal progress, remains evasive.

More than perhaps anywhere else, this complexity is apparent in the context of urban development, where the concept of “smart” cities has become widely associated with ICT and digitalisation (Angelidou, 2015). A range of definitions exist, of course, spanning drivers vs. outcomes, with consideration to organisational factors and spatial features (Yigitcanlar et al., 2018; Lim and Maglio, 2018; OECD, 2020). The scope and novelty of technical applications generally keep weighing heavily: smart sensors, the Internet-of-Things (IoT), deep-learning algorithms and Artificial Intelligence (AI) managed through smart brains, or “orchestrators” collecting, processing and distributing big data (Ahad et al., 2020; Said and Tolba, 2021). Many entail elements of service and product innovation (Walker, 2013).

Smart city applications have been extensively mapped in Europe (Melville et al., 2013) as well as more broadly across the world (Lee et al., 2014; Appio et al., 2019). According to (Duygan et al., 2021), a strong presence of services in the local economy, of universities, and high population density makes urban areas conducive to the adoption of smart city strategies, whereas the size of the city, rate of new residential development or linkages to international networks play less of a role. More fundamentally, however, what activities, and which cities, can be denoted as “smart”, and why does it matter?

An extensive literature observes that the smart city concept continues to be applied loosely (Vanolo, 2014; Meijer and Bolívar, 2016) with multiple connotations to it. Technologies, people, infrastructure, buildings, amenities, and transport may be termed “smart”. Generally, outputs are framed as infrastructure or municipal services that are more resource efficient and supportive of the well-being of citizens.

New means for two-way communication and interactivity are made possible through digitalisation. At the same time, it is implied that the smaller distance between citizens and city governance, compared to nation states, for instance, improve chances that digitalisation helps identify and respond to concrete issues. Yet, the linkages to and mechanisms realising citizen participation are generally referred to in vague terms.

In contrast to the allegations of success, many observers question the relevance of smart city initiatives for conditions on the ground, and the opportunities for most citizens to be heard (Falco and Kleinhans, 2018; Sánchez-Teba and Bermúdez-González, 2018). The critical importance of relevance, i.e., ability to address challenges that matter to the people living and working in the city, have arisen as a critical tenet.

WHAT IS “NEW”?

Institutions tend to evolve along trajectories marked by strong path-dependency, driven by established competencies and vested interests (Wolfram, 2016). In presenting smart city agendas, as noted, governments and urban administrations tend to highlight spectacular applications of new technology. Examples grabbing attention at the present time include “industry 4.0”, IoT, and AI.

From early on, sectoral ambitions featured strongly in smart cities, applying to, e.g., transport and mobility, energy, waste, health services, or tourism. Private sector development encapsulating investment, often realised through public-private-partnership (PPP), is key to mobilising investment and speedy roll-out, while also viewed as key to engaging first-rate competencies, achieving efficiency, productivity, customer-relevance, and fuelling innovation (Scuotto et al., 2016; Deloitte, 2018).

As a flip-side, the smart city agenda is struggling to escape impressions that technical advance and commerce are promoted at the expense of other voices and aspirations. Warnings have been raised against inflicting a culture of conformity, a sheltered space unaccompanied by critical reflection (Swyngedouw, 2007; Catney, and Doyle, 2011). Further, with one-sided rush for novelty, technologies new today will be obsolete and replaced tomorrow, implicating continuous disruption and costs (Saxe, 2019).

This begs the question, what is truly new here? Movements for urban transformation claiming “new” impetus on the urban environment and urban life, have clearly arisen before. In fact, recurrent waves of “modernism” occurred in cities since well before the Roman era (Cugurullo 2018). Generally, though, they were driven by government motives, representing a “supply push”, i.e., authorities or solution providers extending new or revised offers to citizens.

Whether the smart city revolution turns out to be any different remains to be seen. The nature of its roots, as closely linked to digitisation, however, does offer the prospect of realising radically different elements. In fact, the general nature of the crux is clear. Technology does not deliver by itself, and government is not an end. Outcomes depend critically on purposes, including how they are formed, by whom, and whether in the presence of inclusion.

Digitalisation, and the rise of the smart city, is therefore potentially different from the novelties of the past. Its true promise does not reside in the enhanced muscle of government to inform citizens, but rather boils down to unique capacity to propel interactivity, among a broadened range of citizens. Unless the resulting momentum is reigned in, controlled, and manipulated, digitalisation brings the scope for deepening as well as broadening citizen participation.

Although the rise of “smart citizens” – at least as perceived by administrators - displays far less of a convincing record in terms of effective representation by citizens in key decision-making, compared to the influence of experts and business, an increasing number of policymakers, not least at city-level, are becoming genuinely convinced that constructive citizen engagement is both desirable and feasible.

It has been argued that playgrounds are made possible for “[...] counter-discourses through a wider discursive engagement of citizens in the development of the smart city” (Grossi and Pianezzi, 2017, p. 84). Many claim efforts of creating an environment that is open to “[...] practicing user-driven innovation for experimenting and validating Future Internet-enabled services” (Shaffers et al., 2011, p 444).

A related development is the emergence and up-take of new concepts – of Eco-cities or Green cities –placing emphasis on environmental and ecological aspects. There is also the notion of Inclusive Cities, spelling out that citizens, not technologies or businesses, are taking centre stage.

DIGITAL ENABLERS

Today, multiple smart city initiatives placed strong emphasis on developing and applying digital enablers as means to massively enhance citizen participation. For digitalisation to support better and more relevant solutions, however, rather than merely informing citizens – those who live and spend their days in the city need to be granted not just the opportunity, but also the ability to take part in identifying the issues as well as the efforts to work out solutions (Greenfield, 2013; Calzada and Cobo, 2015; Mosannenzadeh et al., 2017).

This development is highly visible in the particular sphere of European projects focusing on NBS, i.e., solutions making use of nature and ecosystem services in support of wide-spread economic, social, and environmental benefits (Maes and Jacobs, 2015). Significant resources have been devoted in recent years to enabling active participation by citizens in processes framing and delivering NBS. The results of the rich empirical experience around have been extensively reflected on in a rapidly expanding literature. While various positive outcomes have been observed, most quality with observations of various conditions exerting important influence on what is possible (Renn and Schweizer, 2009; Burton and Mustelin, 2013; Mees et al., 2015; Cattino and Reckien, 2021). Some observe limited value, and even conclude that counter-productive practices tend to dominate and outright hamper sustainable outcomes (Waylen et al., 2015; Mees et al., 2019; Wamsler et al., 2020).

Despite the critical importance of the subject of participation, relatively little attention has been paid to ways forward to craft strategies and operational tool-boxes for promoting constructive broad-based engagement. To fill this gap, the URBiNAT project has set out to devise, test, evaluate, and draw lessons from co-creation of NBS, and their extension to Healthy corridors. Particular focus is placed on deprived areas and engaging marginalised groups –“unusual suspects” who tend to stay on the side-lines. Here, our focus is on how to apply digitalisation in this context.

If operating in isolation, communication using digital tools may have little to offer on such matters. Unresponsible power structures and communication channels coupled with the prevailing dominance of incumbent competencies and interests, as set out above, may impede any significant progress. Given that digital tools can be embedded in comprehensive vehicles, however, specifically devised to support participation, we enter a totally different space. Building the required functionality, we argue, takes at least for four kinds of building blocks; purpose, method, content, and tools (Andersson, 2021a). With “digital enablers” we refer to synchronised packaging and usage of these four elements, where each is tailored to specific situations and users (cf. Figure 1). Critically, methodologies and content should be suited to fulfilling specific purposes, while using the most suitable digital tools applied by the targeted local subjects.

Combinations of building blocks are considered in Andersson (2021a), along with observations of results achieved under varying circumstances. Separately, Andersson (2021b), devises novel applications, selected through close consultation with local task forces featuring citizens in selected study areas of the URBiNAT cities. These applications relate to the portfolio of NBS introduced for deployment in the project, and also their combined more aggregate constructs experimented with to shape Healthy Corridors, with the aim of countering issues of fragmentation and polarisation in each city. In the next stage, further preparation, design, operationalising and assessment will be pursued in parallel across the interlinked cities, with all stages engaging targeted citizens in co-creation as a basis for a joint experimentation and learning process.

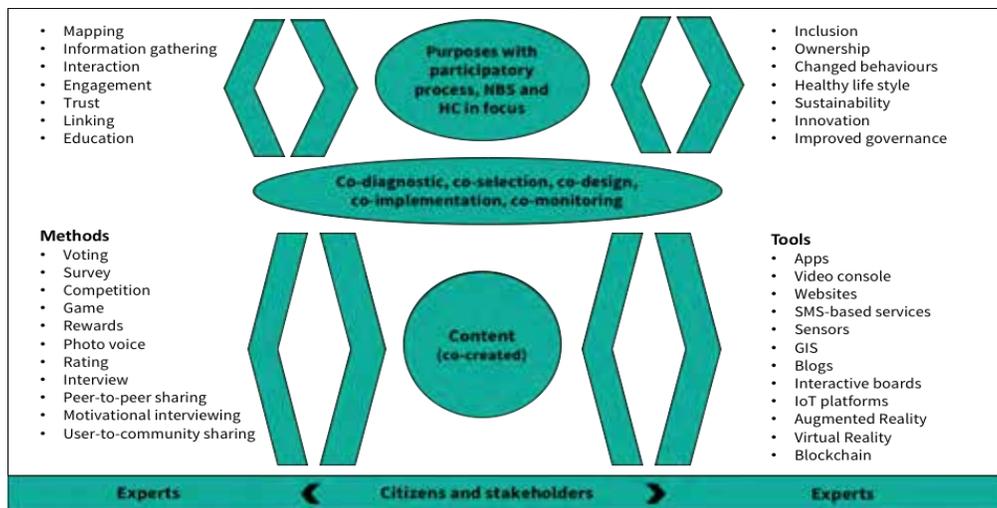


Figure 1: Building Blocks of Digital Enablers
Source: Andersson et al. (2021a)

VALUE-GENERATION

Adequately deployed, digital enablers add value, compared to other means of participation, due to specific advantages, or strengths, in effect the rationale for their application (Andersson et al., 2021a). These include speed, reach and precision when it comes to connecting with large numbers - and also with specific categories - of citizens and/or stakeholders. Notably, suitable methodology and content development offer great scope targeting and tailoring in this respect. Means of linking and strengthening bonds within sub-groups are similarly at hand. Here, so-called Communities of Interest (CoI), can be built upon and leveraged with a view to realising their shared specific interests.

In this, a challenges/solutions-driven approach should be distinguished from one that is identity/strength-based. With the former, focus is placed on bonding in response to common perceived threats, riding on shared fears and concerns. In the latter, positive connotations are picked up, e.g., arts, food, “green”, gardening, or sports. When related to a particular neighbourhood, citizens may mobilise to fortify and upgrade them. Where coupled with enhanced measurement and trusted certification mechanisms, digital enablers may critically underpin enhanced demand for quality including “green” and socially responsible products and behaviours, strengthening support for sustainability through both market mechanisms and pressures on policymakers (McQuaid et al., 2021).

When blended with strong elements of awareness creation, digital enablers may instigate and grow “latent” identities and bonding. Tensions reduced as a consequence may lay new ground for collaboration and compromise among troubled segments of society. On a related note, digital enablers have proven uniquely equipped to introduce operational means of growing collaborative networks (Guerrero et al., 2015; de Vries et al., 2018). Dialogue and cooperation promoted within local communities can serve to reduce dependency on government (URBACT, 2019). A fundamental contribution here is to shift mindset from a narrow “what is in it for me?”, to discover “what is in it for us?” Coming into play are design methods and the framing of participatory processes that operate at community, or group level, with social relations awarded strong attention (Nam and Pardo, 2011). Albino et al., (2015) recommend “integrated approaches” which include both “hard” aspects – technology-based, material compensation – and “soft” (social) rewards.

The relationship between citizens and scientists/experts raises contentious issues, which have been the subject of extensive scrutiny for the purpose of working out solutions to complex decision-making surrounding sustainability and climate change. Participatory practices may deflect attention away from profound, long-term considerations. The need of managing uncertainty and intricate systems aspects inevitably leads participatory approaches into heavy working practices (Hassenforder et al. 2015). Especially when confronted with high-stake issues, boundary lines between facts, values and politics are troubled by the role of media and manipulation by vested interests, as examined by Herman and Chomsky (1988) among others.

With traditional means of collecting and evaluating factual information compromised, the question here is what countermeasures, if any, can be crafted through the application of digital enablers. Digital enablers are surely not a panacea for overcoming risks that warnings by scientists and experts go unheeded, as is evident from the explosion of misinformation and manipulation processed through social media. News coverage in many countries around the world has been reduced to short-form, shallow messaging, benefitting narrow commercial interests and, in some cases, leading to the rise of autocratic regimes.

Going back to Healy (1999), however, extended peer communities are of high importance for establishing trust. Online communication vastly expands the speed and efficiency with which this can be achieved, if properly addressed. This may pave the way for constructive peer-processes and exchanges on terms that facilitate compromise. In essence, digital enablers can be applied to bring about mechanisms for broad-based quality assurance of scientific inputs to policy, operating through ‘extended peer community’ involving citizens at multiple levels while also linking to daily life (Renn and Schweizer, 2009).

Digital enablers can be mobilised in support of improved governance in other respects. Depending on their usage and context, digital enablers may compel local, regional and national authorities to be more transparent and efficient, including when it comes to consultations with citizens and diverse interest groups. The scope for co-creation procedures and the management of public space relates to polycentric governance, taking on board a spectrum of stakeholders. Digital enablers can be framed to support favourable synergies between collaborative governance models (Zingraff-Hamed et al., 2020) and also to cope with influences of multi-level governance (Homsy, 2019).

Digital enablers come with downsides too. Examples include risks of data misuse, privacy violation, proprietary vendors – exploited for elevating populist agendas, or campaigns of influence based on one-sided perspectives, “cherry-picking” benefits readily at hand. Many bottom-up initiatives, emanating from citizens, are trapped by freely available, mainstream social media channels, such as Facebook or Instagram. Gains in terms of accessibility and convenience are extensively compromised by issues of data misuse, privacy violation, and user manipulation (Saad-Sulonen and Horelli, 2017). By contrast, use of platforms that run on open systems, avoiding dependency on proprietary vendors, require substantive effort, investment, and development work, possibly including support by experts in ICT, at least in the short term. On the other hand, the latter put users in control of their own data and development, leaving them less vulnerable to commercial exploitation and with greater development potential. National and local authorities generally lean towards the former, however, explicitly or implicitly playing into their hands.

These conditions underpin the need of safeguards for protecting privacy, enabling adequate authentication and authorisation of IT systems, the rule of law, and civic rights. Innovations have brought some remedial action, including new forms of “digital counselling”, some by the private sector and others by local communities building competencies and promoting measures supporting safety online. Yet, more is required to frame mechanisms for greater control by citizens of personal identities and data (Andersson, 2008; Andersson et al., 2013; Kitchin and Dodge, 2019; Ismagilova, 2020).

RECOMMENDATIONS AND CONCLUDING REMARKS

Taking stock of the challenges invoked by the smart city agenda, this paper focuses on digital enablers in support of citizen engagement and co-creation. The literature is caught in a peculiar trap between a heavy shift in public communication spelling out high ambitions in realising shared governance, and a largely sceptical literature pointing to scanty evidence of positive impacts, and even negative outcomes.

Urban development is marked by relatively few levels separating decision makers and citizens. Against this backdrop, we argue that the willingness and capability of city governance to confront the issues and improve the practices for constructive citizen engagement have in fact shifted from a side-affair to becoming a watershed factor, a defining tenet for smart city designers, as well as urban planners more broadly.

Having said that, governance structured remain plagued by a host of issues. Protective administrative silos tend to underpin traditionally separated centres of power, often demarcated along obsolete divisions of sectoral responsibilities, each marked by their dominant set of incumbent competencies while linked to relevant sets of special interest. Realising tangible progress calls for organisational change and a shift in approach to furthering professional competencies representing diverse perspectives, by way of scientific discipline as well as in terms of practical experience and citizen representation (Wolfram, 2016).

We further observe that digital enablers carry great potential to both deepen and broadening citizen participation. Relatively little attention has been devoted to this capacity thus far, however, and particularly how to operationalise it on the ground. In this paper, we have outlined the scope for embedding digital tools in broader packages of building blocks, while also taking advantage of accumulated experience entailing, e.g.:

- Place emphasis on inclusion and countering conflicting interests, crafting tailored approaches based on thorough local diagnostic, guiding the selection of digital tools carefully fitted with purposes, methodology and content;
- Frame the conditions required for active participation by citizens from the start, with the terms of co-creation consistent and credible over time. In URBiNAT, each of the stages associated with co-diagnostic, co-design, co-implementation and co-monitoring, have been identified as key;
- Ownership by citizens, coupled with accountability, of high priority, relating to both problems and solutions made possible through the application of digital enablers.
- Methods for participation representing a spectrum of well-established engagement practices, such as motivational interviewing, photo voice and focus groups.

On this basis, preparations are under way by URBiNAT for the implementation of selected digital enablers, specifically devoted to frame co-creation that is inclusive of citizens who traditionally were left out. Particular value will emanate from this work being pursued in parallel across interlinked cities, operating in sync with awareness creation and measures on the demand side. Further novel efforts are called for to work out effective ways of mutually strengthening market forces and amending governance structures to include citizen participation on terms that allow for improved quality decisions.

The means of applying digital enablers to help realise more constructive collaboration between experts/scientists and citizens require greater attention and should be actively pursued and seriously evaluated in support of gradual but tangible progress. In framing and running digital enablers, opportunities should be sought to confront the presence of conflicting interests, such as those related to cross-sectoral or cross-border effects.

The present paper calls attention to the great scope that reside in digital enablers for furthering the shift from a traditional Smart-City technology to digital solutions driven by citizens and other stakeholders for advancing and realising the full Eco-city development. This is partly due to the potential role of digital enablers in balancing distributional impacts. For this to be realised, however, adequate and relevant competencies need to be developed, in sync with adjusted strategies and governance mechanisms required for applying digital enablers to both deepen and broadening active co-creation among citizens.

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THE EFFECT OF COVID-19 ON ACADEMIC SOCIAL LIFE IN RIYADH WITH FOCUS ON THE OUTDOOR ENVIRONMENT

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ABSTRACT

On 18 March 2020, the World Health Organization announced that the coronavirus disease 2019 (COVID-19) pandemic had reached global pandemic status. The Ministry of Health in Saudi Arabia implemented a COVID-19 lockdown that lasted for four months. After the period of restrictions ended, people were supposed to return to their normal social lives; however, the lockdown had a psychological impact on people without them being aware of it. This research aimed to study the effect of COVID-19 on social life, mainly focusing on six public activities: visiting shopping malls, mosques, open spaces, interior space, psychological effect, and occupational aspects. The Method survey was distributed during lockdown including the six focus areas and collected using Google Forms. Also, a computer program simulation (ENVI-MET) was used to study and develop an outdoor environment. The research focuses on the outdoor environment to find solutions on a sample used Al Rouda Park in Riyadh. The results demonstrated that people are slowly returning to their social lives during the COVID-19 pandemic by steadily visiting shopping malls, mosques, and open spaces and half of respondents stay at home fearing COVID-19. The research concluded that people should apply health procedures during ongoing time in studied locations and should manage the elaborated psychological effects.

KEYWORDS

COVID-19, sustainability, social life, health and psychological impacts, occupational aspects

INTRODUCTION

Although the coronavirus disease 2019 (COVID-19) lockdown ended in June 2020, people remained at home. A small percentage of people are, however, slowly resuming their social lives. This makes studying the impact of COVID-19 on social life crucial, especially for the three main activities in Saudi Arabia: shopping at malls, praying at mosques, and visiting open spaces. Therefore, accommodations must be made (e.g., shaping the design of interiors and outdoor environments), and studying the psychological effects and occupational aspect is required. The literature reviewed regarding the six focus areas; Echegaray, produced a report that discussed many topics, for example, the post-COVID-19 world, implementing sustainable lifestyles, work, workplaces, family, love, social life, well-being, personal health, education, training, leisure, entertainment, consumption, mobility, housing, living spaces, citizenship, interactions with the state, financial security, social equality, health care provision, and medical reassurances. Among these areas, we focused on the effect of COVID-19 on social life after the end of the lockdown, especially regarding designing interior and exterior spaces, for example, shopping malls and mosques, and its psychological effects on people (Echegaray, F., 2020). Abid, discussed COVID-19 in daily life and stated that it affects social distancing with peers and family; decreases national and international travel; disrupts the celebrations of cultural, religious, and festive events; causes undue stress among the population; results in the closure of hotels, restaurants, and religious places; poor cash flow in the market (Abid Haleem, R. V., 2020). Jiang stated that social distancing involved maintaining 1.5 m between individuals, which can prevent the spread of most respiratory infectious diseases (Jiang1, Meirui, 2020). People can return to their lives by maintaining this distance and can reduce the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by wearing masks and washing hands. The aim of this study is to contextually identify and assess the consequences of SARS-Covid-19 on social life in Riyadh City by the distributed survey to academics in three universities and record their response in designing the interior space, designing the outdoor space, praying in mosques, visiting shopping malls and its psychological effect on people.

LITERATURE REVIEW

Definition of Social Life

Webster stated that social life is defined as the part of an individual's time that is spent doing enjoyable things with others, as investigated by (Webster, M., 2020) Minor stated that Life as a notion that is difficult to define has also been investigated social life is about the existence and the activity of an organic being or the ability to be born, develop, reproduce, and die. The social is what is linked to society: a community of individuals that share a common culture or interest (Minor, M. T., 2018). The following are the tentative parameters that impact health: The impact of designs on interior spaces. Redesigning public spaces. The impact on praying in the mosque. The impact on visiting shopping malls. The impact on psychological well-being. Occupation aspects. We focused on the effects of COVID-19 in five areas, namely, interior, and exterior spaces, mosques, and shopping malls, and the impact on psychological well-being, because COVID-19 has affected these parameters.

Impact on the Design of Interior Spaces

In this regard, Solution discussed the future trends in housing interior design and the associated factors, including building systems, air ventilation, and filtration, relative humidity, and temperature. Figure 1 shows social distancing in interior spaces (Solution, E. D., 2020). Sameh focused on creating resilient cities in Jeddah after the COVID-19 pandemic Sameh provided a webinar on the influence of COVID-19 and quarantine on lifestyle and home design (Sameh, S., 2020). They discussed a webinar regarding the new implementation of green buildings in Saudi Arabia. Riyadh. The capital and financial center of Saudi Arabia was also investigated regarding the challenges facing green buildings; the recommendation was that the focus during the COVID-19 pandemic should be on human health (Al-Serf, M., 2020) Al-Serf discussed how to implement the Internet of things to support sustainability in the Mena region, focusing on smart solutions in green buildings (Al-Serf, M., 2020).

Redesigning Public Spaces

In this context, Scott reported the risks of COVID-19 in the long term and stated that, if left unchecked, there would be a risk that inequalities and social deprivation will increase. However, these risks provide an opportunity to build a better world that should be realized. Scott agreed that the interior and exterior landscapes must be reshaped to ameliorate the risks of COVID-19. Figure 2 shows the different solutions applied in outdoor spaces (Scott, J., May 2020).

Cortêsãoa discussed the sustainability and thermal comfort of public spaces and stated that designers should study thermal comfort in outdoor spaces by studying wind directions, solar angles that provide benefits from trees, and the designs of spaces to provide comfort (Corvacho, H., 2020). Jalal studied the impact of evolving building morphologies on thermal comfort in public spaces in hot, arid climates, and stated that trees and sitting areas with social distancing should be provided (Jalal, O. M., 2020). Jiang also discussed social distancing (Jiang, 2020).

Besides, Echegaray stated that the world is anticipating post-COVID-19 life and the implications for sustainable lifestyles from a Global South perspective

Impact on Designing Mosques

During the COVID-19 pandemic (from Feb.2020 to May 2020), people have rarely visited mosques: some people visit the mosques once a week, others twice, and most of them are not visiting at all. Health procedures were applied in all mosques. Moreover, (Authority, P. H., 2021) and (Health, M., 2021), published the protocols of the Ministry of Health and procedures used inside the mosques, including: Hygiene, physical distancing, and working remotely. Toilets: applying social distancing and supplying liquid soap. Permitting open toilets and ablution places in mosques, provided that a worker is designated to disinfect them after each obligatory prayer. Symptom monitoring and reporting. Increasing COVID-19 awareness in mosques. More cautions were added by the government in Riyadh regarding praying in the mosques during Ramadan 2021, such as regular cleaning, bringing your own prayer carpet. Apply Tawakkalna software.

Impact on the Operation of Shopping Malls

People have slowly started to visit shopping malls, which are also applying social distancing and health procedures. News discussed the health procedures in shopping malls (News, A., 2021). Including: Shoppers must undergo temperature checks at the entrance to stores. They are required to keep two meters away from each other and wear face masks and gloves. Children under the age of 15 years are not allowed entry.

Entertainment venues, cafes, and restaurants in shopping centers are to remain closed according to COVID-19 regulations. Applying the smart application to reduce to measure the number of people inside the shopping mall to be within 50 persons/hours.

Psychological Impacts

On 18 March 2020, the World Health Organization issued a report related to the mental health and psychosocial concerns due to COVID-19 and provided instructions and social considerations to apply during the COVID-19 outbreak. Blue Nile TV presented interviews with famous program presenters affected by COVID-19 and asked them about the psychological impact of COVID-19 and how they recommend overcoming the disease; They said that the symptoms were a headache, coughing, fatigue, a sore throat, and a loss of taste or smell (Blue -Nile., 2020). Prevention stated that the psychological effects started with individuals refusing to admit that they had COVID-19 when the fever started. Subsequently, they took the test and received a positive result. At this time, they began admitting that they had the disease and visited a specialized therapist. There was no specific treatment. The recommended medical advice was to take antibiotics and pain relief and to isolate themselves from their family and the community; this protocol resulted in deep psychological impacts (Prevention, C. O., 2020).

Also, the WHO reported an increasing number of incidences of domestic violence, divorce, and suicide (WHO, 2020).

Occupational Aspects

Neeraj stated that COVID-19 has deep occupation effect on the Academics. Mishar stated that COVID-19 has affected our life, our daily routine, lifestyle, office work and the future plan was interrupted, with focus on occupation it affected how people access and undertake with COVID-19 pandemic, access resources, mobility, social isolation, issues with mental health and well being (Neeraj, M., 2020). Also, Lachan discussed the impact of COVID-19 on the teaching workforce, a new focus on remote learning, new protocols in health and safety, distance learning, working conditions, unemployment in other sectors (Lachlan, L., 2020). In addition Jain highlighted the important of training programs to the teachers to fill the gap in accessibility, usage, and e-teaching and learning skills (Jain, S., 2021). Khogali discussed her university conditions having its own experience regarding the occupational aspect stated that teaching in Saudi Arabia was changed to e-learning as a special case during April to May 2020 and changed to blending learning from Sep 2020 to April 2021, and so were the practical courses on campus, and the theoretical courses online (Khogali, H., 2020).

The Latest Researches in the Field of the Study

Kukenkov discussed the organization of interior spaces using new approaches regarding the assimilation of researched objects, considering color-tonal modeling, and expanding the scope of the organization of space-associated and structural elements (Kukenkov, V., 2020). Gruenwald stated that COVID-19 affected outdoor advertisements in the form of signs and billboards, reporting that we can use QR codes and code names specific to a campaign, along with hashtags on social media like Instagram, Facebook, and Twitter as solutions to this problem (Gruenwald, H., 2021). Freeman discussed COVID-19 and outdoor safety in-depth and highlighted some solutions, such as reducing the number of people entering the public park, staying 2 meters away from others, limiting the access to activities, managing the outdoor space, and introducing mental health agencies to deal with COVID-19-related stress (Freeman, Sh., 2020). Clouston, in this study, suggested how the outdoor transmission of COVID-19 may occur by noting that the risk of transmission of COVID-19 in the summer was highest on days when the wind was reduced (Clouston, S. A., 2021). Lannoy discussed the importance of outdoor space for children and youth, with outdoor play being important for children's physical and mental health; therefore, provincial policies related to COVID-19 and outdoor play are needed (Lannoy, L. d., 2020). Xie analyzed the importance of outdoor space and stated that that urban parks and large outdoor open spaces can provide residents with a place for safe outdoor activities and social interaction in a green environment during a pandemic (Xie J., Luo S., Furuya K., & Sun D., 2020). Barbarossa examined the importance of transportation during the COVID-19 pandemic in Italy to make up for lost time and to start a green revolution that is aimed at quickly decarbonizing urban transport and enhancing cycling and walking through the city (Barbarossa L., 2020). Hamidi highlighted the importance of counties that are tightly linked together through economic, social, and commuting relationships to reduce the number of COVID-19-related deaths (Hamidi, S., Sabouri, S., & Ewing, R., 2020). Batty considered the impact of COVID-19 on the global economy, noting it will need time to recover, maybe a generation, and highlighted the importance of using the new technology and document (Batty, M., 2020) he found that in most countries included in the analysis, park visitation had increased since 16 February 2020 compared with visitor numbers prior to the COVID-19 pandemic (Geng, D., Innes, J., Wu, W. et al., 2021). D'Ascanio highlighted the importance of using of graphic, visual, and multimedia contributions to the landscapes that have been generated in the consciousness of the inhabitants through their perceptions during the quarantine and all phases of the pandemic (D'Ascanio, R., & Mondelli, F. P. editors, 2021). Bravo collected information on this pandemic, including photos and videos. While about 40% of the global population was under coronavirus lockdown, we announced our brand new initiative called 2020: A Year without Public Space under the COVID-19 Pandemic, which was developed in the early stages to help people cope with the health emergency (Bravo, L., & Tieben, H. editors, 2020). Honey reported the importance of using public space for recovery during the pandemic, and cities will be shaped because of the social distancing in the landscape (Honey, J., 2021). Broudehox answered the question: Will the COVID-19 pandemic prompt a shift to healthier cities that focus on wellness rather than functional and economic aspects? The report paradoxically concluded that COVID-19 may also have long-term public health benefits, promoting a more active, self-reliant, and supportive population (Broudehox, A., 2021). Alsutan stated that the international cases of COVID-19 were high, but in Saudi Arabia, the fatality rate had been very low (about 3.8%) because of the strict measures applied by the Ministry of Health and the government, which were followed by citizens (Sultan, F. A., 2021). Abdulmajeed reported that schools and universities need guidance in implementing a clear and effective strategy for students to navigate the coming academic year and expand the academic and psychological counseling, especially for vulnerable populations (Alkhamees1, A. A., 2020). Maryam researched the COVID-19 pandemic in Saudi Arabia and noted the importance of having a research center and calling center for COVID-19 data (Awaji, M. A., 2020). Mark considered the effect of COVID-19 on education in Saudi Arabia and found that most of the schools changed to online teaching and learning; the platform, strong Internet, and mobile and computer devices all are available in Saudi Arabia to 90% of the population, contributing to the success of e-learning education in Saudi Arabia. Mark and Khogali investigated e-learning and teaching in Saudi Arabia. Mark analyzed the effect of COVID-19 on public health, the economy, and migration in Saudi Arabia (Mark, Th., 2021) and (Khogali, H., 2020). Therefore, we believe that the consequences of COVID-19 pandemic crisis could be even more evident. This Novel research will represent new sources of information regarding the interiorspace, designing the outdoor space, praying in the mosque, visiting the shopping malls, and its psychological effect and occupational aspect *on people*. Passing through the literature during the last three years the researcher found that none of this research discussed the duration time of visiting the shopping mall, visiting the park, and praying in the mosque, so at this point, this research is investigating empirical data in this area. Also, Echegaray, Abid, Jianl, Authority, Health, News investigated the health procedures in general during covid-19, (Abid H., 2020), still, this research will investigate the specific area of activities in shopping mall, outdoor space, indoor space, mosques, psychological occupation, and will discuss the health procedures applied by the government and to which extents they are applied, the smart application could be used to minimize the number of visitors toward these places, smart passport showing if the person has taken the vaccine. Solution, Al-Serf, Echegaray, and Authority discussed Natural ventilation, smart solutions in housing, home design, using Colour. This research will investigate more details on this area such as to maximize the interior space, use of plants, practice positive activities at home. Some authors like Scott and others discussed reshaping of outdoor

spaces, advertisements, reducing the number of people entering the public park, transportation, global economy, global societies. This research will investigate more details in Check point should be provided, redesign the grass with social distancing, duration time, the study of the environmental issues by ENVI-MET. Simulation software (ENVI-met version 4.3, ENVI-MET, Essen, Germany). Blue -Nile and other authors discussed the negative signs for COVID-19 such as headache, coughing, fatigue, a sore throat, and a loss of taste or smell Domestic, violence, divorce, and suicide, children’s physical and mental health (Blue -Nile., 2020), (Prevention, C. O., 2020), (WHO, 2020) and (Freeman, Sh., 2020). On the other hand, this research will investigate the positive activities that could be applied at home or in the out space for better recovery of COVID-19.

RESEARCH METHODOLOGY

During the research timeframe from April 2020 to September 2021,

- A survey was distributed using the Google Forms software. The form recorded the responses from visitors to shopping malls, a mosque, and open spaces. The aim was to collect 282 individuals’ responds as a sample for each focus area. there were three main questions about the duration, the health procedures, and the psychological effect of COVID-19.
- The survey had 15 questions in total focusing in four main areas Sustainability, smart solutions, techno cultural solutions and health proceadures.
- Simulation software (ENVI-MET version 4.3, ENVI-Met, ENVI_met GmbH Kaninenberghöhe 2, 5136 Essen Germany) was used to analyze the urban areas and environmental issues (ENVI-MET, 2021). ENVI-met was used to study the environmental issue in Al Rouda Park in Riyad, Saudi Arabia.
- The social life survey was distributed to academics at Dar Al Uloom University, Prince Noura University, and Prince Sultan University; professional groups on social media; students in secondary school. We targeted 282 people from the four areas. There were 141 respondents, including staff members, professors, teaching assistants, students, and professional engineers, which accounted for 50% of the sample. The survey was distributed again to increase the number of responses during March 2021; 141 responses from people in academia were received.



Figure 1. Flowchart of the research method plan to determine the effect of COVID-19 on the social life in Riyadh, including five focus areas: the impact on interior and exterior spaces, mosques, shopping malls, and psychological health

Research Hypotheses

COVID-19 is affecting the design of interior spaces. COVID-19 is affecting the design of outdoor spaces. COVID-19 is affecting praying in mosques. COVID-19 is affecting visiting shopping malls. COVID-19 has psychological effects on people. COVID-19 has occupational effects on Academics.

RESULTS

Figure 6 to 35 shows the results in percentages, distributed amongst the five possible responses: strongly agree, agree, average, disagree, and strongly disagree, more questions were offered. The survey was distributed from 30 September to 30 October 2020. Then, re-distributed during March-2021.

The self-reported responses of visitors to a shopping mall during the COVID-19 pandemic were collected. Of the respondents, 92% applied the health procedures, 50% would not go inside the shopping mall because they were afraid of contracting SARS-CoV-2, and 5.5% visited the shopping mall once per week.

The self-reported responses of visitors to a mosque were collected. Of all the respondents, 59.5% would not enter the mosque because they were afraid of contracting SARS-CoV-2, 15% visited the mosque, 80% of those that visited applied the health procedures, and 8.5% of participants visited the mosque once per week.

The self-reported responses of visitors to a park were collected. Of all the respondents, 29% visited the park once per week, 36% would not visit the park, 17% applied the health procedures, and 44.6% would spend time in the park itself because they were afraid of contracting SARS-CoV-2.

The self-reported responses on changing interior spaces were collected. Of all the respondents, 94% changed their interior spaces, 36% maximized their interior spaces, and 27% opened the windows to improve ventilation.

People spent their time during the COVID-19 pandemic practicing their hobbies and working from home. Specifically, of all the respondents, 41% were teaching online, 38% were watching television, 41% were using social media more than usual, 30% were walking, 30% were reading, 5.5% were visiting neighbors, 2.7% were riding a bicycle, and 8% were listening to the news about COVID-19. The respondents reported substantial hope for the future in terms of the pandemic disappearing and that life would return to normal.

The self-reported responses on occupation 40% of the respondents were practicing teaching online post-covid-19, 20% they were practicing online webinars, also 4% were publishing books and 7.8% were publishing scientific papers, and 23% were practicing the online webinars. 3% of the respondents lost their jobs, 19% of the respondents have no financial resources.

The result from simulating the solar radiation in Figure 39 presented in red is the highest temperature (22 to 25°C) between the block buildings, the orange indicates 20 to 21°C; the yellow represents 19°C to 20°C, and green is the lowest temperature, between 15°C and 19°C. The prevailing wind direction is northwest, at 8 mph, and the humidity is 30% in March. Figures 6 to 10 show the results of the survey distributed to the Academics.

DISCUSSION

A lockdown was implemented in response to the COVID-19 pandemic continuing during July and August 2020. Some individuals continued to stay at home, while others were slowly resuming their social life. Thus, studying the impact of COVID-19 on people's social lives is crucial, especially regarding the three main activities in Saudi Arabia: visiting shopping malls, mosques, and open spaces. A survey was distributed on 30 September 2020 and collected on 30 October 2020; it was then redistributed on 15 March 2021 and collected on 31 March 2021 to increase the number of responses. The total number of responses was 141. The first question was on age. The survey had five groups: 10 to 20, 21 to 30, 31 to 40, 41 to 50, and 51 to 60 years. The second question was on professions. Most of the respondents were students, a few were doctors or teaching assistants, while others were lecturers, professors, and engineers, most of the respondent are living in Saudi Arabia and few are living outside Saudi Arabia. The first focus measured the response of the visitors regarding the shopping malls, mosques, indoor spaces, and outdoor spaces. The survey measured the duration, health procedures, and psychological effects and Occupation. Alsutan stated that the international cases of COVID-19 are high, but in Saudi Arabia, the fatality rate has been very low because of the strict measures applied by the Ministry of Health and the government and people have followed the instructions (Sultan, F. A., 2021). Through the survey, we found that in six areas (interior and exterior spaces, shopping malls, mosques, parks, and occupation), the health procedures were applied to answer the hypothesis questions.

Managing Interior Spaces

Regarding hypothesis 1: COVID-19 is affecting the design of interior spaces.

(Kukenkov, V., 2020) discussed the organization of the interior space by considering new approaches to the assimilation of researched objects and color-tonal modeling, expanding the scope of the organization of space-associated and structure elements. Their research result agrees with ours. COVID-19 affected the interior space, most of participants answered yes to the question regarding whether they changed their interior space, while few said no; most of the respondents managed their interior spaces, they added plants, opened windows daily to provide cross-ventilation, and sports activities. The research found that few changed their apartment because someone was affected by the virus. During the lockdown due to the COVID-19 pandemic, most people spent their time in their homes. As a reflection of this situation, people could change their interior spaces to fit their everyday activities. In addition, opening the windows for cross ventilation twice during the day it is very important to refresh the air. The conclusion: humans are adjusting to the circumstances. At the beginning of the lockdown in Saudi Arabia, the government did not allow people to go outside, except for at specific times (curfew), such as to the market or pharmacy, from February to April 2020. People were performing their jobs and sports activities from home and participating in online meetings or webinars. After three months, the government allowed people to walk around in their neighborhood. Daily natural ventilation for one hour in the morning and the afternoon was necessary to change the oxygen inside homes. Additionally, well-being could be increased by maximizing spaces and adding plants. Figure 1 shows the management of interior spaces during the COVID-19 pandemic.

Visiting the Park

Regarding hypothesis 2: COVID-19 is affecting the design of outdoor spaces

COVID-19 affecting our safety and health, (Freeman, Sh., 2020) discussed COVID-19 and outdoor safety in-depth, highlighting solutions such as reducing the number of people entering public parks, staying 2 m away from others, limiting the access to activities, managing the outdoor space, and introducing mental health agencies to deal with COVID-19-related stress. We agree with all these points, and we encourage checkpoints at park entrances to check the safety procedures and to encourage people to walk and practice activities in the park. This study suggested that outdoor transmission of COVID-19 may occur, noting that the risk of transmission of COVID-19 in the summer was highest on days when the wind was reduced. Our findings agree with this result and we encourage the use of computer programs to study environmental issues. Another study applied ENVI-MET software to study the environmental issues and the solar effects on the surrounding buildings, reporting an increase in the temperature of the building's roof and the facing elevations, suggesting a green buffer zone between buildings and parks, especially high trees. (Freeman, Sh., 2020) and (Lannoy, L. d., 2020) discussed the importance of outdoor space for children and youth, with outdoor play being important for children's physical and mental health; therefore, provincial policies related to COVID-19 and outdoor play are required. We agree with this result. Also, our study of the Al Rouda park, as an example of an outdoor environment, provides a play yard for children and youth, this research is concentrating on the duration time, how many times you visit the park

(Xie J., Luo S., Furuya K., & Sun D., 2020) and Barbarossa (Barbarossa L., 2020) discussed the importance of transportation during the COVID-19 pandemic in Italy to make up for lost time and to start a green revolution that is aimed at quickly decarbonizing urban transport and enhancing cycling and walking throughout the city. We agree with this result, as few people were using bicycles, highlighting the importance of walkability and riding bicycles instead of using public transportation to reduce the spread of the pandemic. Honey noted the importance of using public space for recovery during the pandemic, and that cities will be shaped because of applying social distancing (Bravo, L. & Tieben, H. editors, 2020). Our findings agree with this result, and we encourage people to practice their activities at home, such as sporting, reading, dancing, painting, watching TV, playing games, and spending time with family. Geng stated that the results for most countries included in their analysis showed that park visitation increased since 16 February 2020 compared with visitor numbers before to the COVID-19 pandemic (Geng, D., Innes, J., & Wu, W., 2021). D'Ascanio stated that it is important to ask whether the COVID-19 pandemic will prompt a shift to healthier cities that focus on well-being rather than function and economic aspects (D'Ascanio, R. & Mondelli, F P. editors, 2021). We agree with this researcher regarding this study's focus on health factors in five areas: interior spaces, outdoor spaces, shopping malls, mosques, and psychological effects.

COVID-19 affecting our routine in visiting the park, the research found that most of the respondents reported were never visited the park because they were afraid of contracting SARS-CoV-2. While few reported they visited the park daily. People are encouraged to visit the park and apply the safety procedures. A quarter reported no control point at the park entrances and exits to measure body temperature or check compliance with the health procedures. Figure 8 shows the respondents' responses regarding visiting parks during the COVID-19 pandemic. 5.2.1 Case Study sample in an Outdoor Environment (Al Rouda Park) in Riyadh Al Rouda Park, with an area of about 3200 m², is in the middle of Riyadh.

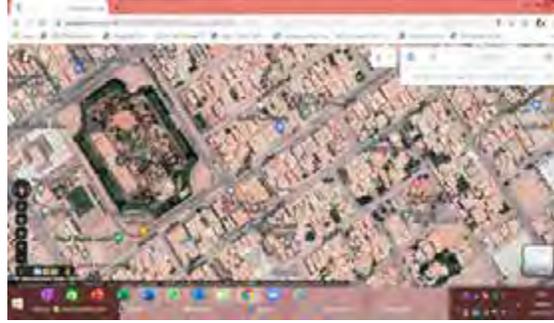


Figure 2. Al Rouda park in the middle of Riyadh is the focus sample for studying the outdoor environment (Google Earth)

The Park provides several facilities for children, and adolescents. There is a sports area and a play yard for football and volleyball. Besides, there are children's play areas and there are sitting areas in seats or on the grass. The most important activity that attracts most of the visitors is the walkway around the park.



The walkway



Sitting area



The grass, which is also offered for families



Stand offering snacks and coffee



The play yard for sports



The children's play area

Figure 3. Facilities in Al Rouda Park, Riyadh

Environmental Issues

This section discusses the wide-area hourly average wind vector (speed and direction) at 10 m above the ground. The wind experienced at any given location is highly dependent on the local topography and other factors, and instantaneous wind speed and direction vary more widely than hourly averages.

The hot season in Riyadh lasts for 4.3 months, from 13 May to 23 September, with an average daily high temperature above 25°C to 44°C in July. The cool season lasts for 3.0 months, from 26 November to 26 February, with an average daily high temperature below 22°C to 7°C Figure 38. The coldest day of the year is 11 January. The average hourly wind speed in Riyadh displays mild seasonal variation over the year. The windier part of the year lasts for 2.9 months, from 22 May to 17 August, with average wind speeds of more than 8.7 m/s per hour. The windiest day of the year is 4 July, with an average hourly wind speed of 10.0 miles per hour. The calmer time of year lasts for 9.1 months, from 17 August to 22 May. The calmest day of the year is 8 October, with an average hourly wind speed of 7.4 m/s per hour. This section also discusses the total daily incident shortwave solar energy reaching the ground over a wide area, considering seasonal variations in the length of the day, the elevation of the Sun above the horizon, and absorption by clouds and other atmospheric constituents. Shortwave radiation includes visible light and ultraviolet radiation. The average daily incident shortwave solar energy displays significant seasonal variation over the year. The brighter period of the year lasts for 3.5 months, from 12 May to 30 August, with an average daily incident shortwave energy per square meter above 7.4 kWh. The brightest day of the year is 21 June, with an average of 8.3 kWh. The darker period of the year lasts for 2.8 months, from 9 November to 2 February, with an average daily incident shortwave energy per square meter below 5.0 kWh. The darkest day of the year is 10 December, with an average of 4.2 kWh. We based the humidity comfort level on the dew point because it determines whether perspiration evaporates from the skin, thereby cooling the body. Lower dew points feel drier, and higher dew points feel more humid. Unlike temperature, which typically varies significantly between night and day, the dew point tends to change more slowly; thus, although the temperature may drop at night, a muggy day is typically followed by a muggy night. The perceived humidity level in Riyadh, as measured by the percentage of time in which the humidity comfort level is muggy, oppressive, or miserable, does not vary significantly over the year, remaining virtually constant at 0% throughout the year, i.e., the climate is hot and dry most of the year. Weatherspark (Park, Weather, 2021). In both summer and winter, people visit parks near their houses. Al Rouda Park is well-designed to encourage daily visitors. The most suitable time for walking, especially during the COVID-19 pandemic, is from 6:00 to 8:00 a.m. and from 4:00 to 6:00 p.m. There are no crowds at these two times. There are no checkpoints to measure personal temperature.

Simulation by Using ENVI-MET

Using a simulation program, the thermal image of the park was studied, with wind direction, and temperature at the microscale. For example, ENVI-MET software is a program used in the design phase that helps to reduce the urban heat surrounding the park by adding more trees and water features.

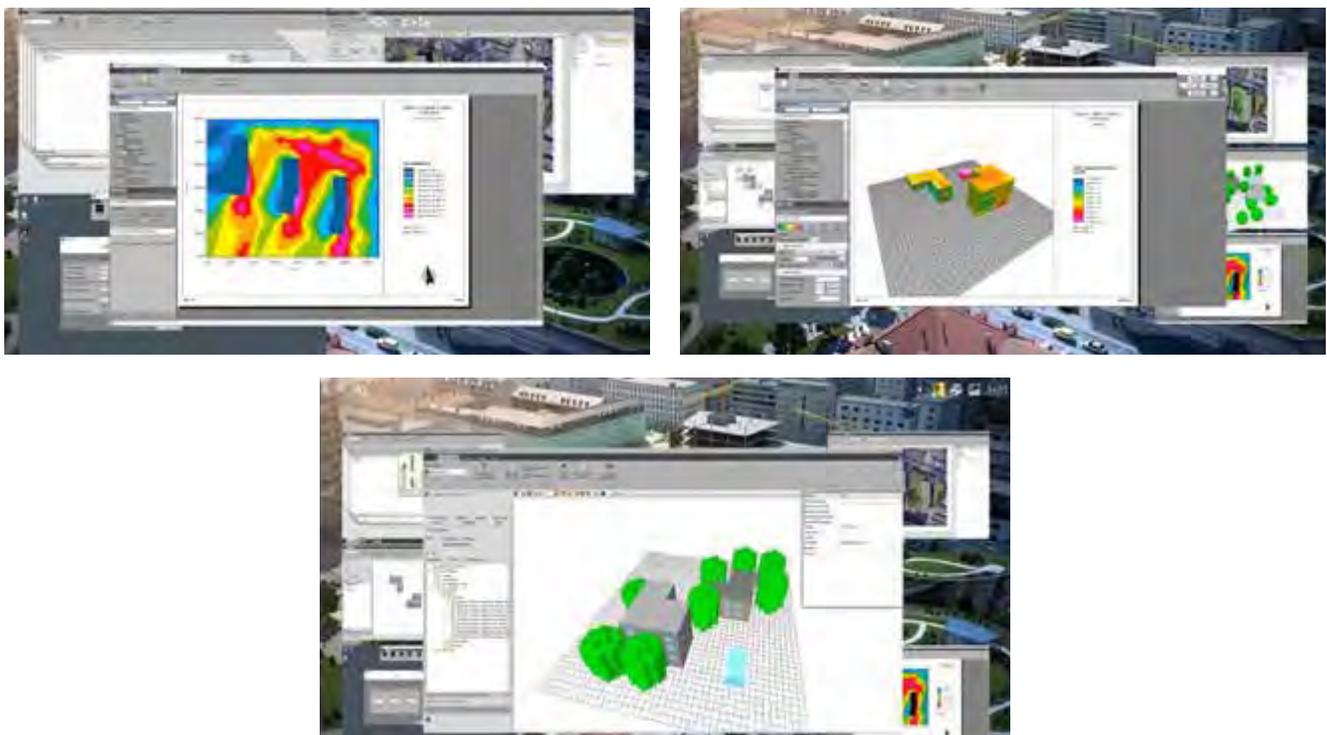


Figure 4. ENVI_MET (ENVI-MET, 2021) software program analyzing environmental issues

ENVI-MET software was used to study the environmental issues in the park, such as temperature, humidity, wind direction, and solar radiation, to identify potential solutions for exceeded temperature especially in summer such as planting tall trees to create a buffer zone between the buildings and the park to reduce the temperature. The solar radiation in Figure 15 presented in red is the highest temperature (22 to 25°C) between the block buildings, the orange indicates 20 to 21°C; the yellow represents 19°C to 20°C, and green is the lowest temperature, between 15°C and 19°C. The prevailing wind direction is northwest, at 8 mph, and the humidity is 30% in March. It is important to plant high trees as a buffer zone between the park and the surrounding buildings to minimize the temperature, especially in summer.

The recommended health procedures regarding COVID-19 in parks include checkpoints near the main gate and main entrance. Notably, most parks in Riyadh, such as Al Rouda Park, have not had checkpoints during the COVID-19 pandemic. The Tawakkalna application was implemented by the government for entrance to all public spaces, which should be downloaded on personal mobile phones and presented at the checkpoint to ensure that a visitor is not infected with the virus (Prevention, C. O., 2020). Checkpoints in parks should be provided during the COVID-19 pandemic to ensure the health procedures are being applied, such as checking personal temperatures using smart devices and wearing a mask. People, including children and youth, should visit the park weekly for walking and practicing sports, as fresh air is required for their health, especially during COVID-19. People should be encouraged to use bicycles within their neighborhoods. Software such as ENVI-MET should be used to study environmental issues, such as temperature, humidity, wind direction, and solar radiation to provide solutions for exceeded temperature especially in summer furthermore, tall trees should be planted to create a buffer zone between the buildings and the park to reduce the temperature. Outdoor fans should be used in summer to increase the walkability of Riyadh. Health procedures should be applied to all park visitors. Some effective design solutions should be applied in the park such as, Figure 16 shows some effective solutions in designing the park during COVID-19 by applying the social distancing in the seats (b), Amphitheatre (e), drawing circles in the grass for families with social distancing (a), and drawing specific path for walking and running (d). Figure 5 shows some effective solutions in designing the park.



a. circles on the grass for sitting



b. Social distancing on seats



d. Drawing specific path for walking and running



e. Social distancing in the amphitheater

Figure 5. Shows some effective solutions in designing the park post-COVID-19

Mosques

Regarding hypothesis 3: COVID-19 is affecting praying in mosques.

COVID-19 affected visiting the mosque, more than half of the respondents reported they never visited the mosque because they were afraid of contracting COVID-19. Other's respondents reported visiting the mosque once per week, some visited the mosque twice per week, others visited the mosque three times per week, and a few visited the mosque daily. Respondents reported that health procedures were applied in the mosques, such as the measurement of temperature, providing sanitizer, and wearing masks. Few of respondents reported not attending because they were under 12 years old. Thus, health procedures were being applied in the mosque and, figure 7 shows that most of the respondents said that social distancing was applied in the mosques, Figure 6 shows the social distancing between the prayers about 2 m as distance. Each prayer brings his own Sigada. Also, the total number of visitors is decreased per hour. The public awareness of the health procedures has increased.



Figure 6. Shows the social distancing between prayers about 2 m in the mosques

Shopping malls

Regarding hypothesis 4: COVID-19 is affecting visiting shopping malls.

COVID-19 affected visiting the **shopping mall**, half of the respondents agreed that they did not visit shopping malls because they were afraid of COVID-19 affecting our daily routine, most respondents reported visiting the shopping mall once per week, other respondents said that they did not visit the shopping mall (Table 3) because of financial issues, a few answered that they lost their job, while others reported that prices had increased. For the health procedures. Most of the respondents reported sanitizer being placed near the front door of the shopping mall. Most of the respondents reported that social distancing were applied in the shopping malls. Also, respondents reported measurements of body temperature by a smart meter at the front door were applied, and few of the respondents reported that their temperature was not measured at the front door. Figure 6 shows the results of the respondents for the shopping mall questions: COVID-19 affecting our safety and health. Table 3 Shows the duration time of the respondents visiting the shopping mall, the results show that zero vistors the shopping mall everyday, and most of the respondents visted the shopping mall once per week, this mean that COVID-19 stric people to practice their everydayactivities.

Figure 7, photo (a) shows the social distancing is applied in shopping malls, also most of shopping malls design reception room to apply the health procedures such as testing the temperature by smart device and wearing the mask. In addition, the numbers of visitors are decreased per day.



a)



b)



c)



d)

Figure 7. Impact of COVID-19 on shopping malls. Source: (News, A., 2021)

Psychological Effects

Regarding hypothesis 5: COVID-19 has psychological effects on people.

COVID-19 affected our health, more than half of the respondents said that they were affected by COVID-19. COVID-19 affected our family functions and relations they described their family as functioning much better, few said that their family functioned much worse during their infection, and few reported no difference in their family's functioning. Others reported that their family provided support for them, and more than half said the family support was a little better. Also, they reported that they were in a good mood, others of the respondents stated that the family support was no more than usual, and others reported that the family supported them as much as they usually did and had average feelings. More than half were not losing confidence and few reported average feelings. COVID-19 has psychological effect, more than half of the respondents reported that they did not visit parks, shopping malls, or the mosque because they were afraid of COVID-19 affected our daily activities, the last question in this part was about engaging in hobbies at home during and after the lockdown. Of the respondents, more than quarter started reading, walking, or dancing; others used social media more than usual; a few took part in sports. Also, they listened to the news on the television about the COVID-19 pandemic, others reported watching movies on television, a few of the respondents said they published scientific research, and few published books. Notably, a few reported riding bicycles. This finding has two meanings: riding bicycles is uncommon in Saudi Arabia and that people spent most of their time at home. The respondents said that they participated in webinars, taught online, and/or were playing video games, and a few were visiting neighbors. Thus, people rarely visited each other during the COVID-19 pandemic. Figure 10 shows the results of how people spent their time during the COVID-19 pandemic. They were practicing their hobbies, such as reading, sporting, walking, and writing. When comparing the results for the five areas, more than half of the respondents reported that they were not visiting these areas because they were afraid of contracting COVID-19. Although the survey was distributed twice, in April 2020 and in March 2021, despite one year passing, the results were still the same: more than half were still afraid of contracting COVID-19. Here, we studied the psychological effects of COVID-19 on people, and it found that it has deeply affected people it constrains them to come back to their social life, most of the respondents reported that because they were afraid of being affected by the COVID-19. We encourage people to practice their hobbies in the interior space and exterior space. The last question on the survey was an open question. People wrote their opinions on the effects of the COVID-19 pandemic on social life. One respondent said: "May God keep the epidemic from us, and may God heal their patients, and have mercy on their dead ... Oh God, Amen."

5.6 Occupational Aspects

Regarding hypothesis 6: COVID-19 has affected the **occupational** aspect.

Fifty percent of the respondents reported that they were practicing teaching online post covid-19.

While about quarter they were practicing online webinars, also, few were publishing books and others publishing scientific papers, and less than quarter were practice the online webinars. When asking the respondents, why you did not visit the shopping mall? Few of the respondents reported '*Because I lose my job*', other reported '*I have no money*'. COVID-19 affected the work condition for example schools and universities. During the lockdown in April to May 2020, Saudi Arabia applied e-learning in schools and universities as a special situation. Now we come back to universities and applied the blending learning from September to April 2021. This highlights the importance of applying training program to teachers to face these challenges in the accessibility, new teaching strategies in the online teaching and learning, Quality Matter principles, improvement of the Student Management system. (LMS). COVID-19 has deep psychological effect on people, half of the respondents reported they were never visiting the shopping mall, the mosques, and the park because they were afraid from covid-19, they should practice positive activities while they are staying home. COVID-19 has deep impact on the workplace, in safety and health procedures such as social distancing, wearing the mask, measuring the temperature by smart devices. Table 4 shows the effect of COVID-19 on occupational aspect and the best practice. Table 1. The results for the five focus areas: interior space, exterior space, mosques, mall, psychological effects, as well as the three focus questions about the duration, health procedures, psychological effects in March 2021

Table 1: The results for the five focus areas interior space, exterior space, mosques, mall, psychological effects

| | Duration | | | | | Health Procedures | | | | | Psychological Effect | |
|---------------------------------|----------------|----------------|-----------------------|---------------------|-----------------|-------------------------------|-----------------------------------|---------------------------|--------------------------------|-----------------------|-------------------------------------|---------------------------------|
| | Once per Week | Twice per Week | Three Times per Week | Every Day | Never | There is no Social Distancing | There is no Temperature Check (%) | There is no Sanitizer (%) | Everyone is Wearing a Mask (%) | No Control Points (%) | I am Young (Under 12 Years Old) (%) | I am Afraid of the Corona-virus |
| | Yes (%) | No (%) | Maximize the Space(%) | | Plants (%) | Open a Window (%) | | | | | | |
| Managing interior spaces | 83% | 17% | 24.8% | | 18.4% | 33.3% | - | - | - | - | - | |
| Visiting parks | 29% | 4.2% | 7.8% | 7.8% | 44% | 12% | 0% | 0% | 14% | 25% | 0% | 50% |
| Visiting mosques | 8.3% | 7.8% | 3.5% | 14% | 59% | 80% | 80% | 71% | 68% | - | 5.6% | 59% |
| Visiting shopping malls | 55% | 7.8% | 2.8% | 0% | 25% | 105% | 128% | 128% | - | - | - | 50% |
| Psychological effects | 30% Reading | 33% Walking | 14.8% Dancing | 43% Social media | 18.4% Sports | 13% TV | 43% Movies | 22% Publishing | 7% Riding a bicycle | 16% Webinar | 27% Video games | - |

CONCLUSION

This study was conducted during the post-covid-19 period in Riyadh, Saudi Arabia, to study the effect of COVID-19 on academic social life. Six focus areas were studied: shopping malls, mosques, interior spaces, exterior spaces, and the psychological effects of the COVID-19 pandemic on occupation aspect. Mosques were applying health procedures by testing temperatures near the entrance doors and applying social distancing measures, and mask-wearing was practiced by most visitors. Most respondents reported changing their interior spaces to fit their everyday activities. The research encourages people to visit the park every day, shopping mall weekly, the government should apply social distancing in seats and grass, control point to check the health procedures by smart devices, the respondents said that to increase their well-being, they practiced activities at home, listening to the news about COVID-19 on television, playing video games. Notably, the respondents rarely visited each other during the pandemic. Regarding the occupation aspect people should keep learning new skills to fulfill the new Challenges by COVID-19. We believe that much research could be done in COVID-19 in the future.

ACKNOWLEDGEMENT

The Researcher would like to acknowledge Dar Al Uloom University, especially the Deanship of Post Graduate studies and Scientific research for funding this research and to my students in course Environmental Control, DAU staff, PNU Staff and PSU Staff for filling the survey. My Thanks should be extended to Dean of College of Architecture and Digital Design and to Arc Scientific Research.

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PEOPLE, PLACE AND PROCESS- OPTIMAL DWELLING AND ENVIRONMENT DOCILITY FOR AGEING-IN-PLACE

Tzen-Ying Ling

ABSTRACT

The key elements of livable environment often include attractive public spaces, walkable, mixed use, higher density neighborhoods that support range of green infrastructure and transport, affordable housing, vibrant, exciting, sociable, human-scaled and friendly pedestrian experiences. Issues such as poverty eradication, health resilience, gender equality, employment and sustainable human settlements are conducive in the reduction of inequality within and across urban centers to promote inclusive living habitat.

However, considering that place-based information on elders' social attributes and place attachment is rare or nonexistent. This article presents the systemic design thinking and prototype framework for optimal dwelling docility for ageing-in-place with the sub-tropic Taipei City in mind. The research concludes that: (1) the resilience process of health and wellbeing must consider people, place and process to attain optimal dwelling; (2) docility criteria incorporate the habitat and environmental enhancement measures, (3) prevailing preference in maintenance of physical space necessitates for stakeholders engaged in improving the ageing-in place community as the core of this study.

KEYWORDS

Environment Docility; Optimal Dwelling; Ageing-in-place; People, place and process

INTRODUCTION

Society has evolved to sustain populations with greater longevity, resulting in demographic ageing in many urban areas. (Sanchez-Gonzales et al., 2020). The global population aged 60 years or over numbered 962 million in 2017, and it is expected to double again by 2050, when it is projected to reach nearly 2.1 billion; while the number of persons aged 80 years or over is projected to increase more than threefold between 2017 and 2050, rising from 137 million to 425 million (UN 2017). Planning for the economic, social, and spatial shifts associated with an ageing population is thus critical and necessitous. Effect of population ageing are particularly pertinent in the promotion of the Sustainable Development Goals (SDGs). Issues such as poverty eradication, health resilience, gender equality, employment and sustainable human settlements are conducive in the reduction of inequality within and across urban centers to promote inclusive living habitat. Interdependence as well as intergenerational solidarity are both tenets of active ageing (Taylor et al., 2018).

Ageing in place (in the home) is a preferred choice and a popular trend for seniors in Taiwan (Chen, 2008; Ku, Chen, Huang, & Tsai, 2018; Lin, 2012). Therefore, residents ageing in place could attain urban identity through familiarity and collective attribution; housing environment holds its own physical and social identity based on its main features and constructed by a collective attribution; mainly, each resident use the self-identification of the city—the built environment with its connotative meanings—influences a person’s identity. Person, place, and process evolves into place attachment: If ageing is to be a positive experience, longer life must be accompanied by continuing opportunities for health, participation, and security (UN 2001). Active ageing places an emphasis on optimizing opportunities for health, participation, and security in order to enhance quality of life as people age (IRC-BR 2015). The concept applies to both individuals and population groups that continue to participate socially, economically, culturally, and otherwise, not just the ability to be physically active or to participate in the labor force to extend healthy life expectancy and quality of life regardless of age or physical condition; thus achieving health resilience within the community. It requires a cohesive linkage of people and environmental support as the core within health resilience. Resilience, however, is a problematic yet promising concept in the living habitat; it has been systematically solicited as an abstractly “malleable” state or settings to attain; in a city, it can allow a flexible adaptive process inclusive of diverse disciplines and stakeholders (Meerow et al. 2016).

The lack of mobility resources impedes the promotion of health and well-being; this prompts a re-thinking on urban planning that incorporates public health issue as part of the process. Indeed, the growing sense of urgency associated with the challenges and opportunities posed by population ageing is evident in the recent proliferation of ageing-related policy initiatives across a wide range of sectors (UN 2015). While is clear in the literature that ‘age in place’ is much preferred, resilient living habitat for the prevailing ageing community demands further attention. Urban age-friendly environments based on action frameworks have been identified, defining approaches and interventions to make cities places that promote the independence of older people (Portegijs et al., 2019; Rogelj et al., 2019; Steele 2015). Knowledge gap in promoting mobility and health resilience as related to people-environment is evident; comparatively less academic research is available on ageing demographic preferences and related environment attributes. The place-based familiarity and environment are key drivers of living preferences, a safe neighborhood, accessibility to amenities, public transport, and mobility should be assessed. This study aims to propose the optimal housing should rely on social and habitat domain of functional ability pertinent to the thematic priorities of ageing-in-place. This study ascertained that: 1) the resilience process of health and wellbeing must consider people, place and process to attain optimal dwelling; 2) docility criteria incorporate the habitat and environmental enhancement measures, 3) prevailing preference in maintenance of physical space necessitates for stakeholders engaged in improving the ageing-in place. Ageing-in place and optimal living consideration toward urban health resilience implication is the core of this study.

PEOPLE-ENVIRONMENT CAUSAL RELATIONSHIP.

Ageing-in-place can be defined as having the opportunity with extensive home support and care services. As residents become frail, the aim is to adapt the home environment with home care assistance in their own homes (Scheidt 2019; Reignier 2018). The dwelling environment or place is conceived as a meaningful location, it is an entity that has a social dimension and a very real physical basis (Reignier 2018; Lewicka 2008). Factors like natural light, landscape features, and design that enables small group clustering should be weighted (Scheidt 2019). Each resident has a different subjective attachment to the city. Perceptions of a city’s identity are equally varied (Nientied 2018) and attention to the topic of urban identity has grown (Scannel & Gifford, 2010; Lewicka, 2011; Evans et al., 2011; Čamprag, 2014; Sandholz, 2017; Nientied 2018). While is clear in the literature that ‘age in place’ is much preferred, resilient living habitat for the prevailing ageing community demands further attention.

Urban age-friendly environments based on action frameworks have been identified, defining approaches and interventions to make cities places that promote the independence of older people (Portegijs et al., 2019; Rogelj et al., 2019; Steele 2015). Knowledge gap in promoting mobility and health resilience as related to people-environment is evident; comparatively less academic research is available on older people's preferences and related environment attributes. The place-based familiarity and environment are key drivers of living preferences, a safe neighborhood, accessibility to amenities, public transport, and mobility should be assessed.

The key elements of livability often include attractive green spaces, walkable, mixed use neighborhood. For higher density neighborhoods, affordable housing with vibrant, exciting, sociable, human-scaled pedestrian experiences could be deemed livable (Shekar 2018). Stakeholders such as ageing residents may lack critical resilience knowledge or thinking; the process allows a sense of empowerment (Ling 2020). Therefore, stakeholders must strive a sense of wellbeing through activities relating to a person's goals, functional capacities and opportunities (Rantanen et al. 2019). Developing understanding of the needs and preferences of ageing societies will be crucial to assist in the provision of suitable housing and communities that are sustainable in the long term (Mulliner et al., 2020). The different theoretical approaches that address people-environment relationships can be summarized in three closely related central themes: 1) places and their processes of meaning creation; 2) identity processes and their relationship with places and 3) the bonds people establish with places, where the concept of place attachment is particularly prominent (Vidal et al., 2010). The people, place and process concept is presented in figure 1 below:

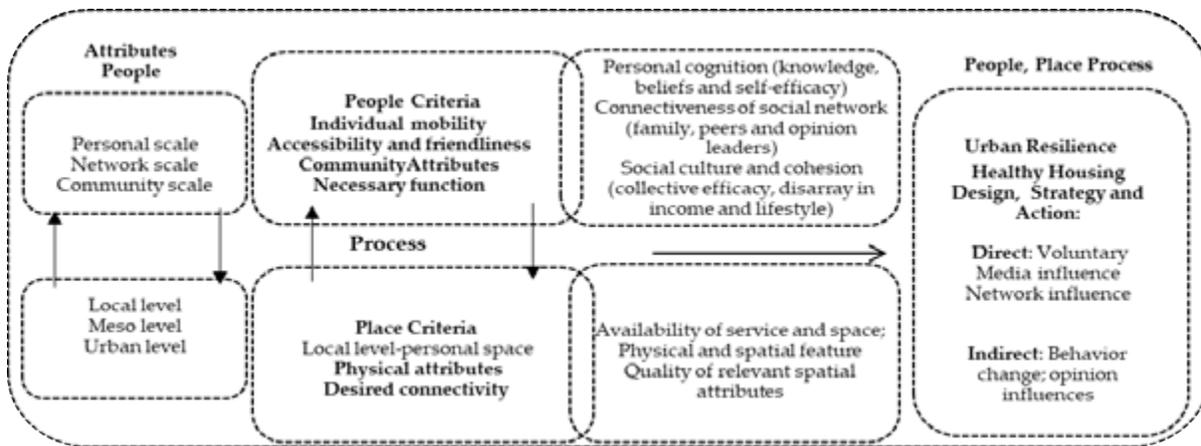


Figure 1 Factors affecting the design of ageing-friendly housing.

The housing environments of older people are recognized as a key factor in determining their quality of life and health (Feng et al., 2018; GOS 2016; Stewart et al., 2014; Garin et al., 2014; Iwarsson et al., 2007), prompting strategies in adequate provision and maintenance to sustain the livability. It is ascertained that age-friendly environments help to foster healthy ageing in two ways: by supporting the building and maintenance of intrinsic capacity across the life course, and by enabling greater functional ability so that people with varying levels of capacity can do the things they value (WHO 2017). In short, the attributes of an age-friendly environment are necessary and needed interventions should be allocated to create more age-friendly community. On one hand, the social relevance dimension places people specific attributes into consideration; on the other hand, the habitat relevance dimension considers spatial attributes to be integrated into a comprehensive assessment. The cohesive interlinkage enables health resilience and foster place-attachment toward an ageing-friendly community. The focus, however, should be placed on the interdisciplinary complementariness in the design of intervention tools applicable to the community and habitat, based on stakeholders' need, environmental optimization and fit to participant needs and preferences (Luciano et al, 2020; Sanchez-Gonzales et al., 2019). To understand the multidimensional ageing-in-place, the input the understanding of the individual micro (person), meso (process), and macro systems (place and policymaking), based on health (prime) environments (Lak et al., 2020) should be examined. However, how the physical habitat can be designed or modified to satisfy the changes at the meso, and macro scale is also necessary in the consideration process.

PEOPLE, PLACE AND PROCESS

Place, like a city, is conceived as a meaningful location, it is an entity that has a social dimension and a very real physical basis (Lewicka, 2008). Each citizen has a different subjective attachment to the city. Perceptions of a city's identity are equally varied (Nientied 2018) and attention to the topic of urban identity has grown (Scannel & Gifford, 2010; Lewicka, 2011; Evans et al., 2011; Čamprag, 2014; Sandholz, 2017; Nientied 2018). The theoretical approaches often address people-environment relationships in three closely related central themes: 1) places and their processes of meaning creation; 2) identity processes and their relationship with places and 3) the bonds people establish with places, where the concept of place attachment is particularly prominent (Vidal et al., 2010). Ageing in place (in the home) is a preferred choice and a popular trend for seniors in Taiwan (Chen, 2008; Ku, Chen, Huang, & Tsai, 2018; Lin, 2012). Therefore, residents attain urban identity through feature of the city based on a collective attribution; each city holds its own urban identity based on its main features and constructed by a collective attribution; mainly, each resident use the self-identification of the city—the built environment with its connotative meanings—influences a person's identity. Person, place, and process encourages residents to place attachment in the physical habitat. Williams and Vaske define place attachment as a superordinate concept with two dimensions: place dependence and place identity (Williams & Vaske 2003) Place attachment imply “anchoring” of emotions in the object of attachment, feeling of belonging, willingness to stay close, and wish to return when away (Lewicka, 2014).



Figure 3. Optimal dwelling consideration taking people-centric positioning to place and process.

Source: WHO ageing friendly housing and this study.

Optimal people-centric position must entail social participation within a positive reinforcement suitable for engage and respond with others; this must be kept within the locality culture and way of life. Aside from the affordability and essential service, which is inherent within the urban system's economy and social capital, community connection, access to service, safety and security, design involvement, probable modification ad maintenance domains fall within the dwelling complex and the vicinity. The term neighborhood is used as a spatial concept as the analysis is partly based on neighborhood characteristics as part of the urban system. For example, the effort to bring natural greenery into urban environments could be the needed incentive to encourage more contact among the residents. This has had a long history within the urban planning doctrine. In the 1850s, Olmsted focused on urban park reform and street design, trying to combine natural environments with urban living spaces [Blodgett 1976]. The greenway movement in the late 1980s was a large-scale concept that proposed creating a green network to give people access to open spaces close to where they live and to link rural and urban spaces in the American landscape (Fabos 1995). Next 21 in Japan is another example of adding green to the building system, animating more contacts and social engagement.

The attachment to place is stemmed from considering location to be meaningful as an entity that has a social dimension and a very real physical basis (Lewicka, 2008). Each citizen has a different subjective attachment to the city. Perceptions of a city's identity are equally varied (Nientied 2018) and attention to the topic of urban identity has grown (Scannel & Gifford, 2010; Lewicka, 2011; Evans et al., 2011; Čamprag, 2014; Sandholz, 2017; Nientied 2018). Cullen (1961) proposed the recording of the sequential order of visual experience, focusing and studying particularly on the town scale. A similar study of sequential visual analysis was conducted along highways, while putting Lynch's five visual elements into practice (Lynch et al, 1964). As the place attachment grows, the process can encourage people to feel or grow accustomed to the place. Currently, cities must answer the demand in planning adequate living habitat for the ageing population. Optimal ageing dwelling should consider a cohesive understanding of how people and place can best benefit a processional dependence and familiarity. As residents become dependent emotionally of a place, whether as an emotional or functional attachment, it reflects how crucial is a place in providing necessary services to support place-specific goals or activities. This attachment, functional or emotional, embodies the area's physical-spatial characteristics or likable living and social interactions.

CONSIDERATION ON IDENTITY AND MOBILITY

The case studies presented in this paper focuses on revised PPP (People, place, process) exploration of place attachment and influences for ageing-in-place; specifically in the attributes consideration to achieve an optimal provision for living-in-place; The different theoretical approaches that address people-environment relationships can be summarized in three closely related central themes: 1) places and their processes of meaning creation; 2) identity processes and their relationship with places and 3) the bonds people establish with places, where the concept of place attachment is particularly prominent.

Taking consideration in how residents identify with the locality is important in an optimal dwelling design or retrofit. Certainly, functional, and emotional dependence are both important in defining a clear identification and attachment to the place. However, the accessibility and mobility must also be consider as one needs to assess the possibility for ageing-in-place. Therefore, residents attain urban identity through feature of the city based on a collective attribution; each city holds its own urban identity based on its main features and constructed by a collective attribution; mainly, each resident use the self-identification of the city—the built environment with its connotative meanings—influences a person's identity. Person, place, and process place attachment: Further, the given identify and mobility of life-space become crucial component in attaining health resilience and age-friendly in the dwelling design (fig. 4)

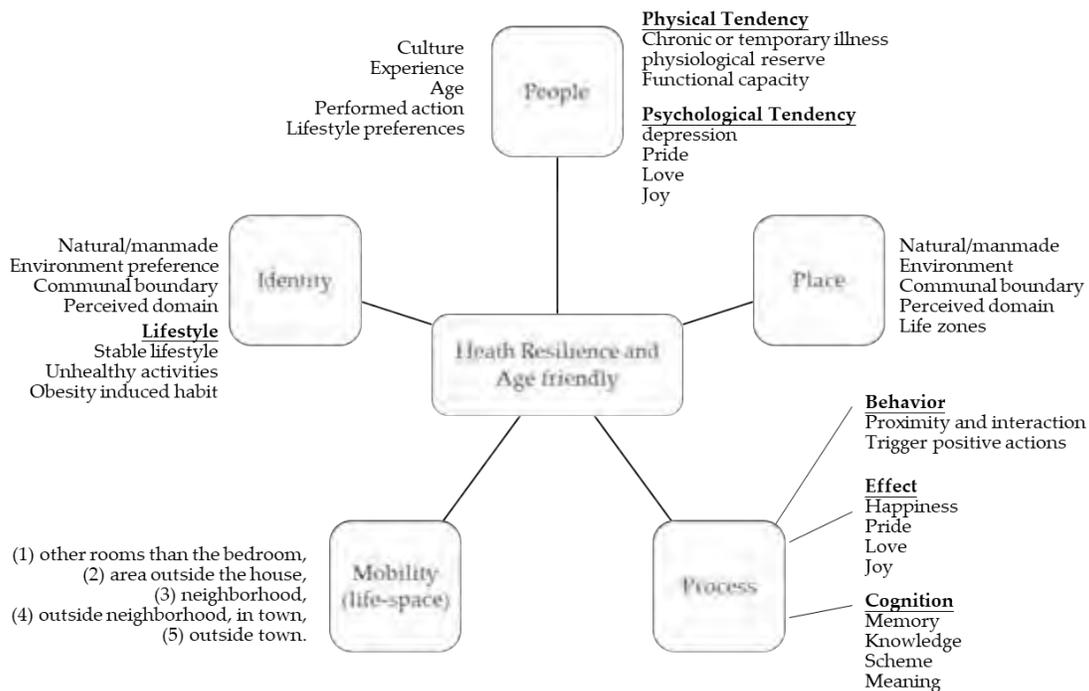


Figure 4. Identity and mobility within the PPP framework

To define residential mobility, we considered gender, age, place of birth and type housing where the residents reside (individual house, block of flats, terraced house, and detached house); family or other members that live together (family, student residence, shared flat or other situations); the length of residence in the region; the city and the neighborhood where they reside during term time. The mobility patterns were summarized in three conditions: local, intra-regional and extra-regional patterns. The local pattern means dwelling in the same city where one studies or in a town located in its metropolitan area. Dwelling in the city where one studies but travelling on weekends and holiday seasons to visit the family residence is referred to as the intra-regional pattern. Finally, the extra-regional pattern refers to travelling outside of the region. The term neighborhood is used as a spatial concept as the analysis is partly based on neighborhood characteristics as part of the urban system.

In optimal dwelling consideration, the comprehensive consideration should accommodate identity and mobility as well as the people, place and process. The overall understanding allows for a resilient design as well as fully considering how behavior, effect and cognition within the process could accelerate the dependence of people on place. As attachment affirms a positive connection or bond between a person and a particular place, the feature or symbolic meaning that local residents may identify and connect with should be recognized. Once the recognition pattern has been established, the identify and mobility attributes should also be considered. The micro to macro scale within the mobility consideration is accrued within the framework. An important feature in place dependence relies on an ongoing exposure or interaction process within a particular spatial-temporal setting. Though local natural-manmade features could foster functional attachment, it could be accompanied by familiar activities or goals, thus forming an emotional attachment as well. Ultimately collected within the lifestyle impression or affirmation that residents have on their domicile or dwelling.

CONCLUSION

People, place and process attributes can easily adapt to multi-criteria assessment in the optimal dwelling provision for ageing-in-place. To accommodate the ageing demographic, urban communities must examine if the dwellings could sufficiently allow for easy interaction and facilitate the livelihood of the ageing residents. Aside from the daily living needs, the spatial provision should encourage residents to conduct in social or health inducive activities crucial to the well-being; however, this is seldom being seriously considered during the design or retrofit process. The people factor seems to be the most taken into consideration; the place factor is taken as a physical site influence, but never taken from the socio-environmental dimension. Therefore, to fully apprehend the people, place and process, the design consideration must incorporate the socio-emotional attributes within the place factor by integrating the process. Further, crucial policies are not present to guide design team or urban management team to assess the spatial and social infrastructure and to prepare design or retrofit strategies.

Communities often need to retrofit public amenities to be accessible to the ageing residents. However, most retrofitting process need to resolve severe spatial-temporal challenges; urban infrastructure must also come to play. Mobility, security are considered important to ageing-in-place but most of the time they are beyond the range of design team, often relying on the public sector for the retrofit. Whatever the place-specific criteria and culture may be, priorities, this study affirmed that “age-friendly housing” should consider the people, place and process model to assess which strategy to take for optimal dwelling habitat. As part of sustainability measure, by integrating people, place and process in the assessment framework, cities could result in more comprehensive and holistic decision making and tie together the gap current being observed. With further study, the assessment framework should be developed into an easily maneuvered model for stakeholders to utilize during the strategy and decision making process within the optimal ageing-in-place dwelling provision context.

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THE IMPORTANCE OF PREVIOUS EXPERIENCES OF RESILIENCE IN COMMUNITIES EXPOSED TO SOCIO-POLITICAL VIOLENCE IN COLOMBIA TO ENRICH THE CBDRR MODEL

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ABSTRACT

The model of Community-Based Disaster Risk Reduction (CBDRR) focuses on traditional knowledge and the specific coping strategies that communities use to manage risk. These coping strategies include the knowledge and mechanisms generated by traditional cultures and previous experiences of these groups. The purpose of this work is to demonstrate the importance of previous experiences of resilience in communities exposed to socio-political violence in Colombia in the establishment of risk management practices and to enrich the CBDRR model. In Colombia communities suffer a double-affectation: those who were affected by natural disasters are also the most socially vulnerable due to poverty, marginalization, and socio-political violence. This study employs a qualitative design that integrates a literature review of the academic field, in-depth interviews, and focus groups with the objective of identifying the processes of community resilience developed by the victims of violence and their contribution to disaster risk management. The study concludes that, as found in other investigations aspects such as, community cohesion, mobilization, political resistance, and collective empowerment permit communities to take the first step in transforming their social status from victim to political subjects that can mobilize and make claims through collective action even when facing risk of natural disasters.

KEYWORDS

Community-Based Disaster Risk Reduction (CBDRR), resilience, violence, affectation, coping strategies

INTRODUCTION

Community-based disaster management (CBDM) is a model that involves the participation of communities in risk by planning and identifying the potential risk associated with decision making, problem-solving and risk reduction, and final implementation in disasters. The CBDM considering the communities as the main experts of their vulnerability conditions, being active participants to take better decisions oriented to their well-being.

However, the practice of risk management in Colombia follows the top-down risk management approach where public institutions prepare, respond and recover in emergency situations.

The Colombian case represents an opportunity to capitalize the experiences, well documented, and related to the contribution of the process collectives: collective identity, community cohesion, attachment to the territory, trust in local leaders, political commitment- social, collective empowerment, collective memory processes, and mutual support practices [1, 2, 3, 4]. In victims of armed conflict, resilience can be a fundamental starting point to connect the CBDM to the work with populations that suffer a double-affected situation.

One of the approaches of the Colombian experiences of these actions is the community of “La Primavera”, located in the Metropolitan area of Medellín city, near to “El Hatillo” district, in the municipality of Barbosa, between the left bank of the Medellín River and the north highway of the department of Antioquia, Colombia. This community was affected by the armed conflict, and the risk of natural disasters for more than four decades [5]

The purpose of this work is to demonstrate the importance of previous experiences of resilience in communities exposed to socio-political violence in Colombia in the establishment of risk management practices and to enrich the CBDRR model. This, through a qualitative design that integrates a literature review of the academic field, in-depth interviews, and focus groups with the objective of identifying the processes of community resilience developed by the victims of violence and their contribution to disaster risk management.

For this, the study identified three of the axes as a category to analyze and collect the information based on the review of literature: (1). Community cohesion and organizational processes, (2). Leadership, solidarity, and community participation, (3). Empowerment. The results were grouped into three main sections: (1). From victims’ associations to risk management practices, (2). Leadership, solidarity, and community participation, (3). Empowerment is a basis to articulate with government and non-governmental entities. Thus, the article is structured as follows these categories presenting in the first place a review of the state of knowledge about different perspectives of risk management in natural disasters, after that, the article explores the association between resilience and double affectation (natural disasters and armed conflict) then, describes the study’s methodology followed by the results and testimonies of leaders and members of the community of “La Primavera”. Finally, our study discusses and presents conclusions about the community resilience process in double-affected communities, their implications, and future perspectives in the field of risk management.

Community-based disaster management a twist in the paradigm of risk management.

Community-based disaster management (CBDM), community-based disaster risk reduction (CBDRR), community-based disaster risk management (CBDRM), or community-based disaster preparedness (CBDP), covers different stages which include preparation, response, and recuperation in emergencies. [6]. This model involves the participation of communities in risk by planning and identifying the potential risk associated with decision making, problem-solving and risk reduction, and final implementation in disasters.

The purpose of all of these is to reduce the response failures by community’s agreement, considering the communities as the main experts of their vulnerability conditions, being active participants to take better decisions oriented to their well-being. For that, communities make an exhaustive evaluation of different threats which are exposed, their specific vulnerabilities, and capacities that will be the baseline of their activities, projects, and reduced risk programs [7].

Therefore, CBDM aims to prepare communities to respond to unexpected events, through their active participation in local government and voluntary support. This implies empowering the local population, considering different causes of vulnerabilities, transforming social, economic, and political structures that generate inequality and underdevelopment, and strengthening coping mechanisms to adapt local capacities [7, 8, and 9]. In that sense, communities become active subjects to face disaster

management and create scenarios that allow them to develop their own strategies and appropriate them, in addition to gaining self-sufficiency and appropriation of risk management strategies. That permits to reduce the impacts and risks of disasters through community participation, becoming the people at the center of development [10, 11].

However, community participation not only focuses on CBDM processes but also on their content, they gain control of their environment as a criterion to guide the decisions and actions of governments and public administrators. [7, 12, 13, 14, 15, 16].

CBDM is people- and development-oriented model, viewing disasters as a matter of vulnerability, focus on community empowerment processes than causes of vulnerability [17]. The key factor of the CBDM approach is the participation of communities, this guarantees the sustainability of the community's initiatives for disaster reduction. [6].

The results of the risk management processes by the CBDR model are remarkable, in terms of reduction in deaths and loss of property, especially in developed countries [12, 18]. The strengthening of local capacities starts from the recognition of community ties, understanding common, values, practices, perceptions, and interests [7, 13]. These aspects were overlooked in previous disaster studies [19, 20]. Community-based perspectives are based on existing local knowledge and experience, as well as resources and people's coping and adaptation strategies [8, 21, 22].

The current acceptance of this approach reflects the significant changes in the risk management discourse has undergone in recent years, from being reactive and top-down to becoming proactive and focused on the community; and also, shifted its priorities from disaster risk reduction (DRR) to community-based disaster management (CBDM), enhancing the community resilience to natural disasters [7]. This translates into risk management based on local resources and capacities to reduce vulnerability [18, 23].

The change of paradigm was originated from the failures identified in the top-down risk management approach. This including 1. Low success to characterize the needs of the vulnerable population [7], 2. The transition from a linear development to major setbacks in the last decade in terms of growth and human development, related to catastrophic events of all kinds [24], 3. The increase in the occurrence of disasters and related losses is due to the exponential increase of the frequency of events, on a small and medium scale.

This approach focuses on, community-based resilience management as a dynamic process of positive adaptation to face significant adversity and traumatic events, "it should be conceived as a dynamic process:

This process permits to build capacities that allow people and communities learn to live into a changing context and manage it to continue developing in uncertain and unpredictable circumstances" [24].

This provides mechanisms to the community that permits to keep the development and maintenance of skills and resources no matter the experience of adversity [13, 16]. This would build the concept of "community is resilient", it refers to a community that "knows how to use synergistically all the resources and available to protect its livelihoods against threats, using the ancestral knowledge transmitted from generation to generation to use the modern early warning systems". [24]. However, in the Colombian case, risk management is framed in the traditional top-down approaches, focus on the response to disaster risk reduction (DRR), without considering clear elements of CBDM, and not with the aim to create resilient communities.

In the Colombian case, the approaches of the resilience concept have been leading from the academy and the practice in different scenarios, particularly, in highly documented processes of the recovery of the population victims of the armed conflict, leaving important learned lessons that can be used in the risk management scenarios.

Double affectation: the process of resilience in victims from Colombian armed conflict.

Previous studies, in Latin American contexts, highlighted the importance of some collective processes for the resilience of communities exposed to political violence [4]. One of the most relevant factors for these populations has been collective memory. Authors has found that memory exercises transform pain and restore the dignity of victims instead to stigmatize them. In addition, they create the context to ask for their rights of truth, justice, and reparation [2, 4, 25, 26]. This also promotes the resignification for those people that did not expose to these events, committing them to non-repetition practices. This constitutes a symbolic instrument to fight not to forget these actions (collective amnesia and state oblivion) and against the official-hegemonic histories of the winners [2]. It also suggested that art pedagogy enhances memory through the recognition of the truth, facing the events of armed conflict, and contributes to the symbolic reparation of the victims [25].

Spaces for mutual support that take place in the community-based organizations have enabled victims to redefine adverse experiences and rebuild the social fabric [26, 27]. In addition, it evidenced that the communicative actions permit the assertive expression of fears and pain, enhance the community ties and self-management through communicative and affective reciprocity, their own stories and the others around the conditions of adversity, solidarity, and empathy, collective resilience is made possible [28, 29]. For example, victims of sexual violence, have built resilience due to family and community networks, where the sisterhood between women emerges. Additionally, psychosocial support and government aid promote their positive adaptation and mental health [30].

In general terms, the construction of support networks in the resettlement places is vital for victims of forced displacement in Colombia. For that, the community provides resources such as food, supports to take care of children, the construction of houses, and even, spaces to develop recreational activities [31]. The aid comes from neighbors, relatives, and religious, educational, health, or NGO institutions that operate the territory; creating networks with these institutions, and bonds of trust and solidarity to face stress [32]. In some cases, community-based organizations even create dialogues with the State and non-governmental organizations, asking for the rights of the displaced populations by the development projects around their food needs (for example, community kitchens), business starter strategies to improve the physical environment (infrastructure) and struggles for land restitution [32,33,34].

From a psychosocial approach of resilience [35], noticing the importance of political subjectivities to denaturalize the conditions of domination, injustice, or violence that affect the victims, and assuming themselves as citizens who can influence the social order and public life [4]. Also, community resilience reinforced the organizational practices that involve planning and structure of actions. These practices usually have a socio-political component that involves negotiations in formal and informal settings, as well as approaches to institutions and management of power relations within the group [36].

Meneses, Moreno, and Narváez, [37] evidenced that social humor (promoted from community theater) is also a positive coping strategy that promotes a cognitive change, particularly, in the representations of reality and violence, reducing the stress situations associated with conflicts, and searching solutions, through mocking criticism of the institutions, exposing their ineffectiveness and motivating the neighbors to work collectively to solve the problems, moving into an interactive place instead of a passive place.

To summarize, research of resilience processes with victims of armed conflict in Colombia evidence the role of collective memory, mutual support, community participation and organization, communicative and affective reciprocity, family, governmental and non-governmental institutions support, political subjectivities, and social humor. This indicates that communities have an active role in resilience processes, which is consistent with the idea, defended by the CBDRR model, which emphasizes the experiences, capacities, and knowledge of the communities, being a fundamental pillar for risk reduction processes.

This article evidences the processes of community resilience in populations exposed to socio-political violence such as the case of the community of “La Primavera” which promotes after-event processes of risk management.

METHOD

This study employs a qualitative design that integrates a literature review of the academic field, participant observation, focus groups, and in-depth interviews with the objective of identifying the processes of community resilience developed by the victims of violence and their contribution to disaster risk management.

To collect information, we use in-depth interviews with community leaders of the settlement, to select the key informants, we consider these inclusion criteria: at least, 10 years in the settlement, having been victims of the armed conflict, and actively participating in victims’ associations, leading processes risk management in the community, interest in participating in research. All of these guarantee reliability and in-depth knowledge of their context. Another strategy to collect data was the focus groups with community members, identifying risk, vulnerability, and resilience factors in their territory.

The study considered three basic axes in which community resilience is expressed in the case of the victims of the armed conflict in Colombia as categories to analyze: (1). Community cohesion and organizational processes, (2), leadership, solidarity, and community participation, (3). Empowerment. These categories made it possible to compare previous processes of resilience, derived from the victimization of the community of “La Primavera” to manage the risk.

This paper is a product of the research project “Vulnerability, resilience, risk of communities and supplying basins affected by landslides and avalanches” code 1118-852-71251, project “Determination of sociocultural and psychological variables of vulnerability and resilience derived from stress events due to disaster risks of origin natural or anthropic”, contract 80740-492-2020 signed between Fiduprevisora and the University of Medellín, with resources from the National Fund for Financing science, technology, and innovation, “Francisco José de Caldas Fund.

“La Primavera” settlement

“La Primavera” settlement is located between the left bank of the Medellín River and the north highway, and near to “El Hatillo” district, in the municipality of Barbosa, 42 Km approximately from the metropolitan area of Medellín. Noticing that the settlement is built on a gas pipeline, under a high voltage tower, and next to the old railway line.

In 1978 arrived the first inhabitant of “La Primavera”, after that, according to the reports of Corporación Región (nd), there were identified four periods of the settlement process. Figure 1 presents the different stages of the community settlement of “La Primavera”.



Figure 1: Chronology of the settlement of “La Primavera”

49.6% of displaced families resettled in “La Primavera” come from different municipalities of Antioquia (Anorí, El Bagre, La Pintada, Ituango, San Jerónimo, Ituango- Vereda El Aro, Segovia, Taraza,). Followed by 45, 9% who came from the Metropolitan Area (Bello, Barbosa, Itagüí), and neighborhoods of Medellín such as Zamora, Santo Domingo, San Javier, Santa Lucía), part of them, after other displacement processes. Only 4.3% come from other departments of the country.

Notice that Barbosa experimented with a significant internal displacement process, where some families resettled in La Primavera.

Additionally, the risk situation affected the capacity to carry the territory, which has resulted in an undermining of the banks of the Medellín River, which is aggravated by the exploitation of the river’s resources.

On the other hand, the arrival of new settlers due to offer houses for rent to displaced people and migrants such as Venezuelans has generated difficulties of coexistence and tense relations between leaders, due to the uncertainty that rules in the community, the fight for the scarce resources and the absence of the state.

In addition to this, the expectation of displacement due to the construction of the commuter train begins and threatening because of the arrival of new illegal armed actors.

RESULTS

About the victims’ associations to risk management practices

The perception of disaster risk and risk management practices in “La Primavera” was developed after the creation of armed conflict associations of victims that operates in the community. The association: “Asociación de víctimas y desplazados nuevo amanecer los meandros” was built in 2013, only in 2017, the community started to perceive the risk of disaster in their territory:

These risks were very evident in 2017. Before these events, we lived calm and relaxed. We did not perceive that risk (...) with the gas pipe, the gasoline pipe that passes under our houses (...). Since 2017 the river began to eat the shores over here (...) before that it flooded? No, because the river passed far away (...) all of this was full of trees, super beautiful, we lived happily, and suddenly, when the river started to walk here, when the meander there was lost: My God!, serious (...) the course of the river changed. When these people came here and started this, they took our oxygen, my God! (...) The people from the mine ... and they knocked down all the trees (...) And they began to explore the river bed. Then, as

a result of that, they were deviating it towards there (...) When he grows up and goes to go out there, he comes so strong, so he begins to look for his flood zone, because they boxed him in (...) so, we are in imminent risk (...) In the last flood, he got into my backyard. (Interview 1, community leader).

At the beginning of 2021, the community created risk management to coordinate training, alert, and notification activities to the authorities (fireguards, police, and civil defense). A community leader relates about:

We have stretchers, first aids, demarcated routes, and concentration points for any event. We have organized ourselves more or less well, we managed to get the early alarm. All these actions are achievements made by the association (...) there were many drills, and training (Interview 3, community leader).

Before the creation of this committee, the community organized processes of political incidence to achieve resettlement and access to decent housing. This integrates the community, not only start from the perception of the risk of disaster, but also the precariousness of homes that the people live after suffered forced displacement, expecting a better life, and a better place where they feel safe:

What's your objective? (...) A housing project, what we are looking for is resettlement, in a place to start over, put down roots, because most of us are victims of forced displacement due to the armed conflict. So, here we cannot to put down roots, we have no security. (Interview 1, community leader).

The Community members conclude that risk management practices promoted by previous community processes of organization and participation, related to the same interests (i.e. claims for the right to the city and decent housing).

Do the victims 'association, has helped you to face this issue of risk? Or do you see it as two separate processes?

-No, it is the same process (...) we have involved in all areas (...) we already realized that we were already visible, so we had to touch all areas (Interview 3, community leader).

Leadership, solidarity and community participation

Before the existence of the perception of disaster risk, community leaders already had as one of their purposes to enhance the environmental conditions in their territory, through explaining to the community about their relationship with nature, climate change, as well as, the promotion of practices such as recycling and taking care of water sources. All this was possible through playful strategies such as “environmental reign” or community theater actions, where children and adolescents have participated actively.

On the other side, the community has worked to improve the physical infrastructure and its living conditions. For example, they have managed to fix paths and stairs, the construction of spaces to call community meetings (communal house), and have organized the sewerage:

All the roads that have been made by the Community Action Board committee (...), we made all the arrangements. The most important thing that I think was done in this community was to collect all the sewage. Part of it fell down behind our house. (Interview 1, community leader).

Also, it is important to notice that community organization and participation have been promoted by the appearance of leaderships developed with love and commitment. These leaderships have an echo in a community by the characterization and maintenance of the bonds of solidarity between neighbors, providing the mutual support to face the adversities for settling in the new territory as a result of the forced displacement:

This community is very supportive. If someone has a problem, there is a neighbor, the neighbor tells the other, and there it goes like a chain where all people help (Interview 1, community leader).

For example, here someone died (...) they join in the duel, the pain, and all of them are very helpful (...). There are conflicts between families, nevertheless, they are controlled by the good coexistence available (Interview 2, community leader).

In this way, consolidation of leadership, community participation, and solidarity have made it possible to joint actions to improve living and environmental conditions, to build a dignified and resilient life, despite the situation of the displaced persons to live in a territory with high exposure to disaster risk.

Empowerment as a basis for articulation of governmental and non-governmental entities

Over the years, the community looked for the recognition and support of state entities, mobilizing in different ways to generate political incidence around their demands. Initially, they encountered resistance and obstacles, but gradually, through the insistent efforts and support of non-governmental entities, to gain visibility:

I told him, Mr. Mayor: “you know who I am (...) I come from the victims’ association, I know that you as an administrator cannot invest money there because it causes you problems, but there is something you can do for us. Please look at us, we are part of this municipality, we buy food here, vote there, sleep there, we are part of this municipality, so please, see what you can do for us”. What did it help us with? With the bank of materials, he gave us to fix some stairs that had fallen due to an avalanche. (Interview 1, community leader).

In this relationship with the State, the community does not expect assistance responses, they seek a link from co-management:

Due to I am one of those who think that one sitting, doing nothing, cannot wait for another to do for one (...) So I never tell the municipal administration what are they going to do? No, what are we going to do? What can we do? Because it is not them alone, it is us as a community as well. (Interview 1, community leader).

Now, the relations with the State have been improved by the promotion of community empowerment and the training and support processes that the community has had by non-governmental organizations. The support of these organizations is a result of the improvement of the community’s capacities to achieve participation and incidence:

How have you been with the State?

-The relationship with them was null, because we came there and they looked at us like strangers, as if we were less than them, and I learned with the Region Corporation that nobody is more than anybody (...) we all have the same rights (...) But right now they have not been able to forget us [he refers to the mayors of the municipality] because the Region Corporation taught us to make ourselves visible, we are already visible, they already know at all times that we are here. (Interview 1, community leader).

With the Region, we achieved (...) an inter-institutional organization, made by 17 governmental entities, and also popular ones (...) we have them working to see if we achieve what is most essential for “La primavera”: about, the settlement. It has been looking for. We may succeed, or not, but we have to fight, and we are fighting (Interview 3, community leader).

To summarize, previous findings allow us to confirm that risk management practices have been favored by previous processes of community organization and participation, consolidating the leaderships and constructing a social fabric characterized by solidarity relationships.

Also, the demands of the community about the access to decent housing, permit, coherently, to articulate the risk management practices with the displaced population needs, at least to improve their living conditions. Finally, we noticed that the social support received from non-governmental organizations has strengthened the community processes of political incidence, establishing a dialogue with the State concerning the guarantees of their rights as a victim population and the improvement of their living conditions in the territory.

DISCUSIÓN AND CONCLUSIONS

The study concludes that, as found in other investigations [1, 2, 3, 26, 27, 35], aspects such as community cohesion, mobilization, political resistance, and collective empowerment permit communities to take the first step in transforming their social status from victim to political subjects that can mobilize and make claims through collective action even when facing the risk of natural disasters.

The community’s fights to recover their dignity in terms of decent housing and resettlement in a safe territory are consistent with their needs caused by double affectation first, as victims of forced displacement, and second, as a population exposed to disaster risk.

This empowerment of the community seeks to provide solutions to their problems. These aspects were consistent with the approaches of the CBDRR model, suggesting that risk management practices are not be limited to generate palliative measures to face disasters. This was oriented towards the transformation of social, economic, and political conditions that might be associated with inequity and underdevelopment. In other words, look for the transformation of the conditions that produce vulnerability [7, 8, 9].

In our study, community actors have positioned themselves as political subjects who claim their right to the city and decent housing, not from a passive and welfare position, waiting for the government’s offers to solve their problems. They were organized as actors who demand the state recognition, by the participation of public debate scenarios, participating in different institutional spaces of governmental and non-governmental institutions, to generate solutions to their problems.

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ECOLOGICAL IMPERATIVES

The city is committed to sustaining and restoring biodiversity of local, regional and global ecosystems, including species diversity, ecosystem diversity, and genetic diversity. It keeps its demand on ecosystems within the limits of the Earth's carrying capacity and supports ecological integrity by maintaining essential linkages within and between ecological corridors.



WORKING WITH NATURE-BIOREMEDIATION

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ABSTRACT

The relationship between urban development and water is inextricably linked. The very first known developed cities in the world with drains, bathing areas, and a possible well were the ancient cities of Harappa and Mohenjo-Daro, located in Pakistan.

The urban water ecosystem is a core foundation for urban health and is directly associated with the economic development of the region and the quality of urban residents' lives. Evaluating the health of an urban water ecosystem is fundamental to development of an ecologically civilized city.

In the past few decades, rapid transformation of the agriculture to industrial economies has led to various challenges particularly, water pollution and depletion of fresh water reserves. Biological used water treatment, technically known as bioremediation, is one of the most effective methods for the treatment of waste streams and enables reuse of the water for domestic and agriculture applications.

Pakistan's severe water scarcity, limited resources and contamination of freshwater reserve, required to find a cost-effective and sustainable solution to reclaim used-water to save water for human consumption. Since 1997, through various mechanisms the government has tried to manage used-water and move towards water security.

Bio-remediation of used-water for reclamation under National Environmental Quality Standards (NEQS) was discovered when the total submission was made to mother nature to lead. Nature's self-healing mechanism demonstrated that bio-remediation techniques, living organisms like microbial consortia, aquatic plants can help resolve managing used matters efficiently to be a part of mother nature's closed-loop.

More than two hundred sustaining bioremediation models were developed which were successfully applied in urban, peri-urban and rural areas in partnership with corporate, public, and development sector organizations.

KEYWORDS

Bioremediation, Safe water, Ecological imperative, Low-cost low-energy water detoxification

BACKGROUND

“Pakistan is one of the world’s most arid countries and is heavily dependent on the Indus River system. About 180 billion cubic meters of water of the system emanates from the neighboring country and is mostly derived from snow-melt in the Himalayas.” [1]

Plains of Punjab in the subcontinent were known as the granary of the world. In 1947 at the time of partition of the subcontinent Punjab was divided. Ravi, Beas, and Sutlej rivers were now a part of India. India blocked the flow of these rivers to Pakistan in April 1948. This caused huge distress to Pakistan, hence water diplomacy started and both countries under the conciliation of the World Bank negotiated the Indus Waters Treaty (IWT). In 1960 Pakistan got rights to river Indus, Jhelum, and Chenab. This in itself was challenging because these rivers were located in distant location to the plains that needed to be irrigated for agricultural farming.

“Water issues between Pakistan and India were settled through Indus Water Treaty – often regarded as a remarkable example of conflict resolution. But the recent Indian intentions of building “chain of dams” on Pakistani (western) rivers have once again posed a serious challenge for Pakistan. Further, UN reports are suggesting that Pakistan is going to become a water scarce country in near future.” [2]

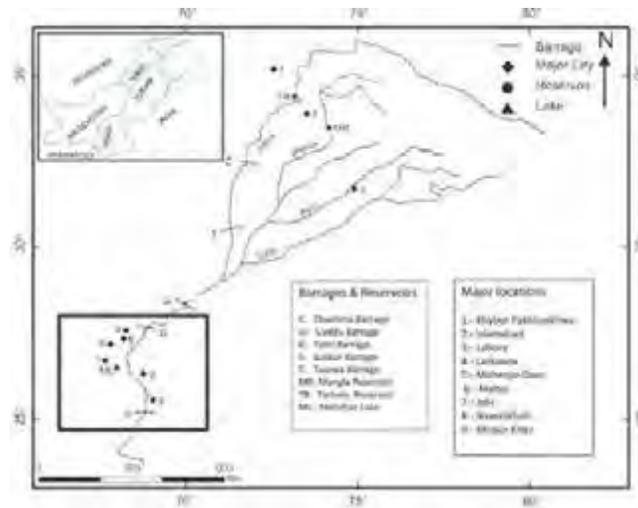


Figure 1. The Indus River in Pakistan. Major cities and locations of important barrages along the Indus River are also shown. [3]

Currently Pakistan is the fifth most populated country in the world with more than 35% of population residing in the urban areas. Historically and at present some of the major cities are located along these rivers. River Ravi is one of the main rivers used for irrigating Punjab’s agricultural land. Replenishing the groundwater table for the cities residents and fresh produce is grown and cattle are reared along these river banks. In recent years due to water scarcity rivers beds are mined for sand.



Figure 2. Mining in Poonch River using heavy machinery is destroying river habitats. Photo: Hagler Bailly Pakistan. [4]

The unchecked untreated waste and used water disposal over the years has caused degradation to the aquatic life and water quality. South Asian fresh water Indus river dolphin is an endangered species. Further polluted toxic untreated – used water from the factories is discharged in drains which runs through the agricultural and populated land. This was causing environmental pollution.

To counter imminent environmental disaster the government set up the National Institute of Bioremediation (NIB) in April 2009. This was established under Pakistan Agricultural Research Council (PARC) and National Agricultural Research Center NARC.

INTRODUCTION

National Institute of Bioremediation (NIB) with a multidisciplinary team comprising of environmental chemist, analytical chemist, soil microbiologist, environmental microbiologist, plant taxonomist, engineers and horticulturist developed models that were economically sustainable and met NEQS.

Bio-remediation and how it works

Bioremediation capitalises the potential of microorganisms and their metabolism to reduce various pollutants in the wastewater with very low energy consumption and capital cost. The microbiological wastewater treatment offers several advantages over the conventional techniques.

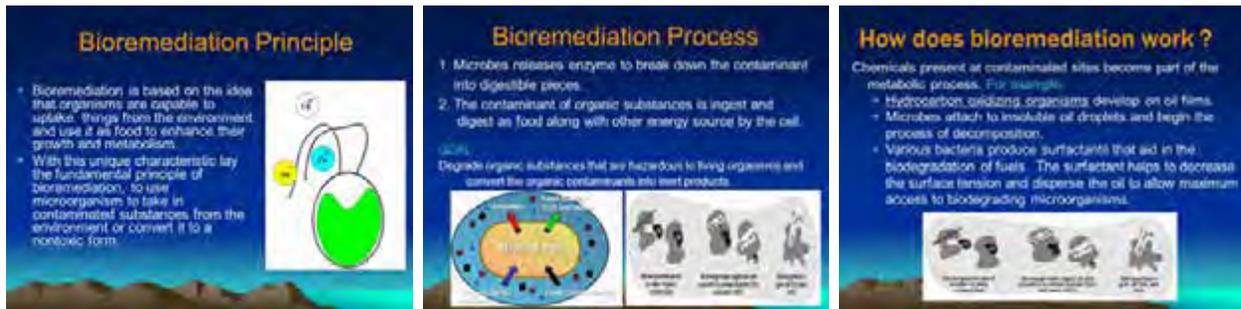


Figure 3. Bioremediation principle, process and its working. [5]

LOCAL MODEL OF BIO-REMEDICATION

The model developed by National Agricultural Research Center (NARC) and Nano Bio-Solutions (NBS) works with indigenous species of aquatic plants. The components and process comprise of following steps:

1. Screening Unit
2. Anaerobic Baffled Reactor
3. Constructed Wetland
4. Phytoremediation & Stabilization Ponds
5. Treated Water Reservoir

Bioaugmentation and bio simulation is applied in anaerobic baffled reactor and constructed wetland.

Bioaugmentation is used to biodegrade specific soil and groundwater contaminants. Cultured microorganisms are added into the subsurface of the soil to biodegrade the particular contaminants. The microorganisms are aimed at obliterating specific target contaminants.

“Bio stimulation is a remediation technique that is highly efficient, cost effective and eco-friendly in nature. Bio stimulation refers to the addition of rate limiting nutrients like phosphorus, nitrogen, oxygen, electron donors to severely polluted sites to stimulate the existing bacteria to degrade the hazardous and toxic contaminants.” [6]

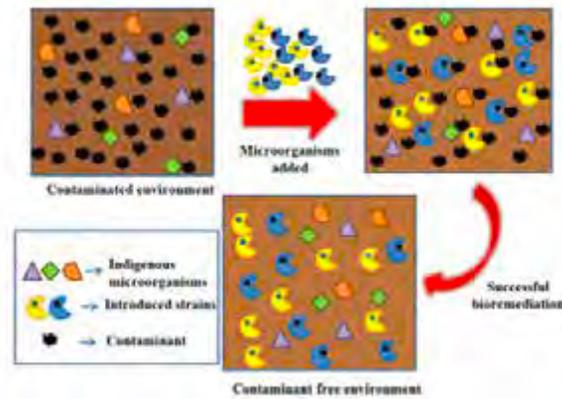


Figure 4. Bio stimulation process for contaminant free environment [7]

Bio stimulation process adds nutrients like phosphorus, nitrogen, oxygen, electron donors to polluted sites to stimulate the existing bacteria to degrade the hazardous and toxic contaminants.

After retaining the water in the constructed wetlands over a period of time then water is treated in the phytoremediation and stabilization ponds. Plants like typha, pennywort, water lettuce, bulrush, water hyacinth, duckweed to name a few are the workforce of these ponds. Local aquatic plants according to the climatic region are employed to reclaim the used water which is transferred to the reservoir of treated water. The treated water is distributed to local peri-urban or agricultural land.

Installation

First the contaminated site is identified, then the level of contamination and containments are documented. Volume of flow is studied and layout is designed accordingly. Peri-urban or rural land is allocated for the construction of bio remedial ponds and chambers. For maintenance and operations local staff is engaged. This process offers value added products.

NIB principally worked in the following principle areas:

- Bio-remediation and Integrated Farming
- Phytoremediation/ Bioremediation

Bio-remediation and Integrated Farming

To meet irrigation requirements and eliminate pollutants in used water to improve the overall environmental health of soil and land, the government was committed to create a model for other stakeholders to follow. This would benefit livestock, poultry, fruits, vegetables and honeybee framing. Reclaiming water and land to improve agricultural productivity. Alternative energy sources as in biogas plants to complete the loop.

Phytoremediation/ Bioremediation

To remove contaminants from water body that effect the water ecosystem like heavy toxins, ammonia, nitrite, heavy metals, phosphorus and bacterial pathogens. Phytoremediation is used for decontaminating used water by using aquatic plants to reduce or eliminate toxins altogether.

“Bioremediation involves treating the organic contaminated material both at the site and away from the site of contamination. More than 20 indigenous plants have been discovered in different climatic zones of the country (Pakistan) for treating used water and reclaiming contaminated soils.” [8]

NIB successfully developed bioremediation model with locally available aquatic plants by April 2010. A team of dedicated researchers from diversified fields worked diligently to accomplish this, working on a low-cost, low energy consuming cycle to reclaim used water under National Environmental Quality Standards (NEQS). The established model was applied to the peri-urban area in the vicinity. This area was declared under threat by Environmental Protection Agency (EPA). NIB treated 0.65 million US gallons of used water which was polluting environment and agricultural land. Reclaimed water was utilized for 500 acres of agricultural land.

IMPLEMENTATION STRATEGY

- Awareness Campaign: Creating public awareness of hazards of untreated waste water entering the food chain.
- Strategic Collaborations: Cooperative undertakings with local, provincial, national & international relevant partners.
- Technology Modeling: Establishing financially & technically sustaining sites.
- Partnerships: Promotion of associations with private, public and development sector organizations.
- Marketing: Promotional campaigns with concerned stakeholders.
- Standardization & Certification: Establishing mechanisms and operating standards.
- In the first quarter of the program the bio-remediation team has capacities to develop function bio-remediation sites for training & demonstration; Three in capital territory, two for each province, one for each AJK and Gilgit Baltistan.” [9]

From 1997 to 2013 sixty-three bio remedial sites all over Pakistan were established by Nano Bio Solutions (NBS). Of these a few were with NARC, Quaid-e-Azam University (QAU) and National University of Science and Technology (NUST) Islamabad. Some of the projects were supported by local and international donor agencies.



Figure 5. Comparative cost analysis of mechanical and bio-remediation system [10]



Figure 6. Bioremediation technology for wastewater treatment developed by Nano Bio Solutions, components and process, cost comparison, projects implemented, list of local aquatic plants, working data and installation



” [11]

BIO-REMEDIATION PROJECTS UNDER NIB, PARC, CDA, UP, QAU

Integrated Sanitation & Farming System (ISFS)

ISFS is used in combination with bio-remediation process to complete the nature's loop. This facilitates used water treatment facilities financially, reusing organic used-matter. This method employs given natural resources by assimilating all constituents to a productive outcome which is environmentally sustainable and financially viable.

Table 1. ISFS integrated with bio-remediation of wastewater utilizes natural resources to complete the loop reusing organic used-matter to facilitate the following processes

| Particular Natural Process | Applying Beekeeping | Aquatic Plants Treatment system |
|---|--|--|
| Used water treatment with microbiological consortia | For pollination of seed and fruits | Use duckweeds for irrigation and protein-enriched food for poultry and animals |
| Constructed wetland | Plankton treated used water for fish | Can be used in bio-digester to enhance bio-methane production |
| Use of UV light and aquatic plants | Grow mushrooms for humans by using by-products of wheat, cotton and rice | Can be used in making different natural compost |
| Animal sanitation to use dung in bio-digester | Use remaining compost as natural fertilizer | |
| Digested slurry for organic farming | | |

[12]

REPLICATION OF THE TECHNOLOGY IN PRIVATE, PUBLIC AND DEVELOPMENT SECTOR

The ISFS/Bio-remediation technology is replicated in all four provinces of the country by private, public and development organizations.

“Establishment of Waste Water Treatment by UNICEF Pakistan, Phase-1

Local Government and Rural Development Department (LGRDD) and Anjum-e-Takmeel-e Maqased-e Inسانيا (ATMI) (1996-1999) Three of the above organizations contributed to introduce various components of ISFS/Bioremediation in Gangu Juma Village, Taxila. The reclaimed village wastewater was about 0.75 cusec, covering approximately 3.5 acre of land. The land used for biological treatment of wastewater was about 0.75 acre and rest of the land was restored for integrated farming activities.



Figure 7. Farming made possible in phase-1 of the project by reusing village wastewater at Taxila

Finalization of Integrated Farming Components, Phase-2. ISFS/Bio-remediation Resource Centre Village Gangu Juma, Taxila. UNICEF Pakistan and Sardar Ahmed Khan Memorial Welfare Trust (SAK-MWT) (1999-2001)

SAK-MWT played important role with the collaboration of UNICEF Pakistan to complete the integrated components. These components include finalization of the landscaping, mushroom production unit, poultry farm, beekeeping, organic farming and fish farming components.



Figure 8. Mushroom production unit, poultry farm, beekeeping, fish and organic farming in a complete loop by reusing village wastewater in phase-2 at Taxila

IBADAT ISFS/Bio-remediation Resource Centre, Lahore. UNICEF Pakistan and IBADAT Trust Lahore (1999-2001)

IBADAT Trust with cooperation of UNICEF Pakistan replicated the concept of ISFS in the village Chamru Pura, Raiwind Road Lahore and reclaim 0.65 cusec wastewater for irrigation.



Figure 9. Reclaimed wastewater from the village used for irrigation near the city of Lahore

ISFS/Wetlands Demonstration Centre, Village Chattal, Chakwal. Plan International and Nano Bio-Solutions (Pvt) Ltd. (2011-2012)

The local community was socially mobilized to contribute for the replication of the concept and 0.8 cusec of wastewater for irrigation and ground recharge.



” [13]

Figure 10. Village locals on self-help basis and with local and international partners, reclaimed wastewater for irrigation and groundwater recharge.

CDA & NARC, PARC Establish Bioremediation Sites at Streams in Islamabad Territory to Clean Wastewater (2014)

The Capital Development Authority (CDA) with the collaboration of Pakistan Agricultural Research Council (PARC) has established Pakistan Bioremediation Model for Wastewater Treatment at Rose & Jasmine Garden and F-9 Park Islamabad to clean the wastewater of streams passing at these places. The treated water is used for green belt and other horticultural activities.



Figure 11. Wastewater Treatment at Rose & Jasmine Garden and F-9 Park Islamabad to clean the wastewater of streams passing through

Bioremediation of Chromium and Arsenic from Industrial Wastewater (Kasur, Sheikhpura and Sialkot) 2011

A project by University of Oklahoma, USA and University of Punjab, Pakistan. The chromium, arsenic and various compounds had polluted the aquatic and terrestrial environment in these industrial zones. The project spanned over several years. Microbial process was used to decrease the health hazard in the environment due to these substances. Appropriate mitigation strategies were employed to decontaminate the soil and industrial wastewater. Over a hundred new scientists were trained and involved in ecological genomics, molecular ecology and anaerobic microbiology through distance learning program.



Figure 12. Leather tanning in Sialkot [14]

MILESTONES ACHIEVED BY NIB

- Bio-remediation Garden to reclaim sewerage water of NARC offices.
- Bio-remediation Orchard for treatment of 0.65 million gallons waste water of Shehzad Town, Islamabad.
- Established integrated farming facilities through usage of reclaimed water at Bio-remediation Garden and Bio-remediation Orchard.
- Small-scale ornamental plant nursery.
- Establishment of scented Rose nursery for perfume extraction.
- Establishment of 30,000 ornamental, fruits and forest plants under high density plantation.
- Established water quality laboratory.
- Production of high nutritive value crops i.e. duck weed, water lettuce from used water for poultry and livestock feed.
- Creating Awareness amongst policy makers, academics, farmers, in print & electronic media, NGO's and members of civil society.
- Established collaboration with media partners i.e. TV Channels, Radio and Print media.[15]

CHALLENGES

Some of the challenges in implementation of wastewater bioremediation treatment system are as follows:

- Promotional and understanding issues with relevant stakeholders, municipalities and rural communities.
- Lack of trained manpower for large scale replications.
- Non availability of aquatic plants harvest & processing machinery in certain zones of the country.
- Issues in customized bio-remediation inputs production.
- Difficulties in provision of effective and living microbial consortia at regional levels and wastewater testing facilities.
- Standardization for replications according to climate zones.
- Certification for replication. [16]

BIOREMEDIATION WASTEWATER TREATMENT SYSTEMS ADVANTAGES

- Compliance to Sections 11 to 14 of Pakistan Environmental Protection Act, 1997 (amendments) which prohibits discharge or emission of any effluent, waste, air pollutant or noise in excess of the NEQS, or the established ambient standards for air, water or land.
- Low capital cost, low operational cost.
- No energy input is required, electrical or mechanical.
- Works naturally with available gravity flow.
- Treatment work force is indigenous isolated microbes and selected plants which decompose and assimilate organic load of the wastewater.
- 100% natural to complete the chain of decomposition in the ecosystem.
- Environmentally friendly, no chemical, or power is used in the process.
- Provides surplus treated water for irrigation of green belts or general-purpose agriculture.
- Hybrid Bio-Technology, uses all indigenous components, less land is required.
- Land utilized, in return can generate extra income through integrated farming which includes mushroom yard, poultry, high density herb and fruit gardens.
- Recreational water park enhancing bio-diversity and landscape.
- Cultivation of vegetables and high valued crops with treated wastewater through bioremediation reduces water related disease.
- “The wastewater production from Pakistan’s urban centres can provide approximately water volume 103.4 million cubic meter/year.
- In general estimation approximately 18.63-million-acre wheat crop can be irrigated annually with the above water availability.” [17]

CONCLUSION AND RECOMMENDATIONS

- Bioremediation model developed locally to reclaim used water by the process of bio remediation- integrated framing and phytoremediation has been successful.
- The integrated farming provides knowledge access to the community in the areas of kitchen gardening, seasonal plant nursery for flowers and vegetables. Water lettuce composting technology. This service by NARC & PARC is benefitting the farmers community but the outreach must increase incrementally for the larger community to benefit.
- The model should be made public by an aggressive campaign and local farmers trained and assisted in implementation and installation.
- PARC to partner with donor agencies to run free training workshops for farmers in peri-urban, rural areas.
- The checks have to be put in by PARC so that the used water by factories or municipalities is mandated to be treated before it is discharged.
- Further import of treatment plants should be reviewed, as seen in the past that the expensive imported equipment is rendered useless in a year or two because of poor maintenance. This is owing to lack of trained staff and the energy or resources required to run it effectively.
- Bioremediation model developed for various climactic zones to be made accessible to public.
- The current challenges of water security and water management could be addressed by the application of integrated waste water systems using microbe as catalysts for removing toxic chemicals, producing bio-energy and improving water availability for the growing population of the world.

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COMBINING THE RIVER CULTURE CONCEPT AND NATURE-BASED SOLUTIONS FOR SUSTAINABLE URBAN FLOOD MANAGEMENT

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ABSTRACT

Nature-based Solutions (NbS) gain popularity worldwide in the context of urban flood risk management. NbS for urban flood protection restore floodplains and lakes/ponds to retain periodic flooding and adopt green infrastructures to facilitate stormwater runoff. They are proven to be effective and able to provide co-benefits for human wellbeing. However, projects to implement NbS are often hampered by institutional challenges and a lack of specific knowledge. The flood catastrophes in European and Asian cities in June 2021 have shown that despite decade-long warnings by scientists, adaptive measures had not been implemented in time. We, therefore, make a plea for combining NbS and the River Culture Concept, an eco-social approach to mitigate the environmental crisis in riverscapes. River Culture recognizes pulsing hydrology as a baseline for biological and cultural diversity and encourages ‘learning from the river’ and ‘living in the rhythm of the waters.’ The aim is to support NbS interventions to improve human-river relationships and transform River Culture Concept into actions. We first compare NbS and River Culture Concept in principles, then produce a list of evaluation indicators with River Culture tenets serving as criteria. We furtherly use the tool to analyze three selected NbS examples in China, Germany, and the U.S.A. The results demonstrate a limited consideration of more comprehensive biodiversity benefits from floodplains and a disparity between using natural flow regimes and meeting human needs in current NbS approaches. Last, we conclude specific sustainability lessons with the combination of NbS and River Culture Concept in urban flood management.

KEYWORDS

Nature-based Solutions; River Culture; Urban flood management; Sustainability

INTRODUCTION

Floods have been the most frequently occurring natural disaster in the past decade. Between 1994 and 2013, floods accounted for 43% of all recorded natural disasters affecting nearly 2.5 billion people [1]. Today, with extreme weather events identified as the highest likelihood risk of the next ten years [2], floods become an increasing threat for cities, where 55% of the world's population resides, recorded in 2018 [3]. Not only taking lives [4], [5], urban floods cause considerable damages, including direct impacts (e.g., physical damage caused to property), indirect impacts (e.g., loss of production, suppliers, and customers by companies), business interruption, impacts on infrastructure (drainage, traffic, electricity, etc.), intangible impacts (negative impact on the mental wellbeing, loss of recreational environments, contamination, etc.) [6], [7]. Many urban flood problems derive from blind faith in flood protective measures, suggesting that upriver barrages or high dikes would entirely overbuild floodplains that previously served as flood retention space. However, these areas are high-risk zones today [8] – comparison of city maps from pre-and post-industrial phases evidence that urban expansion into flood areas is relatively recent. Moreover, since the 19th century, canals and the increasing imperviousness of urban surfaces have been developed to convey surface runoff as fast as possible out of the city. As a collateral effect, these waterproof structures increase flood height and reduce the hydrological buffering capacity of the soils. Grey infrastructures such as dams, seawalls, roads, water treatment plants, pipelines, sewer systems, and storage reservoirs block the exchange of water, air, or animals [9], [10], i.e., they deteriorate the functionality of riverine ecosystems [11]. Given this background, Nature-based Solutions (NbS) emerged in urban water management as a paradigm shift [12] and is increasingly recognized globally and mainstreamed in practice. Inspired and supported by nature, NbS use green infrastructure, defined as an interconnected network of natural areas and other open spaces that conserves natural ecosystem functions, sustain flood water and provide a wide array of benefits to people and wildlife [13]. In densely-populated cities, NbS flood management tends to be implemented in a hybrid way – combining natural features with the conventionally built infrastructures – as they are cost-effective [14], demand less space, and provide broader social benefits [15]. Despite considerable success of developing NbS approach (e.g., EU's Horizon 2020-funded NbS projects [16]), there are still some limitations of the existing NbS projects. Many of them lack broad public participation, are influenced by institutional path dependence, and take years to function appropriately [17]–[19]. Specifically, for NbS interventions that mitigate urban river floods, trade-offs are often made between the interest of humans and non-human biota. This study aims to improve this type of NbS with the help of a socio-ecological concept: River Culture [11], which combines biological strategies (i.e. adaptive species traits) with cultural adaptations from traditional communities, applying innovative technical and administrative processes in river management. We hypothesize that urban NbS flood management should comply with River Culture principles to achieve long-term sustainability. We make a plea to combine the (more technical) NbS approaches with the (more theoretical) River Culture and suggest developing sustainable measures for urban hydrosystems. First, we compare the two concepts and set a list of evaluation indicators based on River Culture tenets. Next, we use it as a tool to evaluate three NbS examples, illustrate their performance and make corresponding recommendations. Finally, we draft conclusion of combining the two for the improvement of NbS' sustainability and for the enhancement of River Culture Concept through tangible actions.

NBS FOR URBAN FLOOD PROTECTION

Emerged initially from the 2000s in integrated pest management, NbS referred to using habitats to mitigate farm runoff in agriculture [20]. From 2009 onwards, the term became widely used to increase resilience to climate change impacts [20]. As an umbrella concept covering a range of ecosystem-based approaches such as low impact development (LID), water sensitive urban design (WSUD), sustainable drainage systems (SuDS) [21], NbS has been enriched in scopes and framing. NbS are defined as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits” by IUCN [21]. IUCN further developed a Global Standard for NbS, including design at scale, biodiversity net-gain, economic feasibility, inclusive governance, balance trade-offs, mainstreaming, etc., to help effective NbS design in society [22]. In terms of flood protection, NbS have evolved from technical and engineering methods to measures with little intervention to ecosystems [23] and are proved to be effective in the reduction of stormwater runoff and peak flow [12], [24]–[26]. In contrast of the traditional grey approaches to ‘keep water out’, NbS flood management respects the dynamics of the hydrological system, leaves spaces for flood retention, allows percolation of surface discharge to recharge groundwater (‘let water in’), and offers more ecosystem services and biodiversity [27]. Urban NbS flood management functions through 1) restoring floodplains and the river-floodplain connectivity; 2) constructing artificial ponds and lakes; 3) small interventions such as green roofs and facades, tree planting, bioswale, rain garden, permeable pavement. Depending on the spatial context, these options can be implemented together or

as alternatives. Additional values, i.e., co-benefits, are realized via the multi-functionality of these floodplains, wetlands, and lakes, notably recreation if they are open public green spaces (Fig. 1). Conflict may arise between habitat conservation and recreation in floodplain areas, and water stagnation in lakes, ponds may negatively affect human health by contamination. Therefore, successful NbS often require trade-offs (Fig. 1).



Figure 1. A Venn diagram of NbS for urban flood management: different-scale measures, their related requirements (adjunct text in green), and relationships. Graph by Y. Cao.

Restoring floodplains and river-floodplain connectivity

Floodplains are areas that are periodically inundated by the lateral overflow of rivers or lakes and/or by rainfall or groundwater [28]; river and floodplain are one integrated system that has evolved over time to convey water and sediment downstream, with the floodplain serving to both store water and slowly releases it back into the main river channel as the flood passes [29]. Therefore, decreasing connectivity between the main channel and the floodplain habitat, caused by human-made concrete structures such as levees and dikes (i.e., grey infrastructure), or river bed incision, is a critical threat to biodiversity in both instream and riparian communities [30] and conversely increases the flood risks. Therefore, NbS make spaces for floodplains to function and re-link them to adjunct rivers. In modern cities where the open public spaces along the river are often limited and fragmented, successful practices largely depend on the spatial and socio-economic context [27]. An example is *Room for the River Programme* in the Waal river in Nijmegen, The Netherlands (2012-2016). To construct a new river channel and floodplains, the project relocated the dikes 350m inward with demolishing around 50 houses through a long process of negotiations and compensation for the property owners [31]. On the other hand, for many cities with increasing density, especially in Global South where different social and biophysical pressures occur simultaneously on the urban hydro systems and cause a ‘catastrophic’ situation [8], large-scale restorations of floodplains in urban contexts have been rarely implemented due to the lack of an integrated urban planning and weak governance [8]. An example is the ‘*River Regulation Zone*’ and ‘*River Conservation Zones*’ proposed by Prof. Brij Gopal in India; the idea is to regulate and forbid industrial activities up to 5 km from the riverbanks [32]. However, little implementation has been seen due to unclear responsibilities on water and land between state and respective States/Union territories.

Constructing artificial retention ponds and lakes

Urban ponds and lakes are inland water bodies surrounded by a built environment [33]. They are widely used in stormwater management as they can temporarily store runoff to reduce the peak flow and provide additional water resources [34], [35]. Additionally, if well managed, they can support high species richness [36], [37] and produce multiple ecosystem services [38]. In Canadian cities, ponds are increasingly constructed for flood risk reduction (e.g., over 200 ponds in Ontario and over 500 in Toronto [39]), and incorporated into the new design of urban residential areas since 2003 [40]. The design of artificial stormwater may include a permanent water level (retention ponds) or periodical filling after rainstorms (detention ponds) [33], [41]. Detention ponds are designed to maximize their storage capacity; the culvert/pipe for outflows is placed at the bottom of the ponds to constantly drain the stormwater out, making the volume available for the next storm event. Retention ponds generally contain permanent water bodies with permanent water levels that are supported by the groundwater table, and the

culvert/pipe for outflows is installed above the bottom. Ponds and lakes store stagnant or slow-flowing waters, trapping, filtering sediments [42]. Due to the longer hydraulic retention time, retention ponds permit those finer sediments may settle down and are removed from the outflowing water. This may reduce clogging of water conduits and avoid flooding in the downstream sections. Nevertheless, as long retention time could deteriorate the water quality and result in eutrophication [43]. Regular drying-up of the sediments allows mineralization of organic matter and facilitates sediment removal but does not support fauna and flora requiring permanent wetting. Urban lakes and ponds require regular maintenance, e.g., planting of phosphorus-accumulating plants in the early stage of construction [44]. In Canada, the urban ponds are well managed by measures such as regularly removing sediments on impervious surfaces and improvement of the water quality before the water enters the pond, by introducing rain gardens, bioswales, and constructed wetlands [39].

Realizing additional values via multi-functionality

In cities where the available land for restoring natural floodplains is unavailable, partial floodplains and/or artificial ponds and lakes are often transformed into floodable open spaces with recreational amenities to offer multiple human uses. Such water-retention parks can carry floodwater during heavy rain and provide additional recreational values during non-flood seasons. For instance, the Waal River project in Nijmegen (mentioned above) built a river park on the newly-formed island in the city's heart [31]. Examples also include the Bishan Ang Mo Kio Park of the Kallang River Restoration project [45] in Singapore, Cheonggyecheon stream in Seoul, South Korea [46], and Yanweizhou Wetland Park in Jinhua, China [47], all of which became the new landmark of the city and tourist destinations. However, recreational activities in cities potentially conflict with the ecological values of restored floodplains as they are likely to disturb habitats for sensitive fauna and flora, such as the case of the Isar River in Munich, Germany [48] and the Kallang River in Singapore [49]. Therefore, regulations on human activities and visitor-management plans to balance biodiversity conservation and recreational services are needed.

Limitations of the NbS approach

To facilitate NbS implementation for urban flood management, trade-offs are often made between humans and non-humans (resulting in a low biodiversity value [50]) and among stakeholders (due to differences in co-benefits perception and valuation [51]). In practice, the trade-offs may cause NbS projects that invest in non-native monocultures [50] and create diverse patches of green spaces in the city with a lack of connection [52]. In the long term, this can lead to NbS' maladaptation under a rapidly changing climate [50]. Additionally, potential conflicts between different co-benefits beneficiaries may lower NbS's acceptability and lead to increasing trade-offs [51]. This ideology reflects an anthropocentric position that only values nature's contribution to achieving a good quality of life for human beings. The most commonly used economic valuation of ecosystem services is deemed rooted in an anthropocentric, classic utilitarian approach [53]. To challenge this principle for NbS' sustainable development in managing urban hydro-systems, we thereby propose combining NbS with River Culture, a concept seeing cities as co-evolving human-natural systems, do not give priority to human development [54], adopt local knowledge of flood adaptation and involve wider stakeholders in riverscapes' management [11].

APPLICATION OF THE RIVER CULTURE CONCEPT IN URBAN WATER MANAGEMENT

The River Culture Concept [11] critically examines the common understanding of floods. The natural flow regime of rivers includes regular and occasional inundations as a natural phenomenon that supports dynamic river-floodplain ecosystems and has been a life-giving force for riverside human societies for centuries. The problem of floods being considered “catastrophic events” arises from the increasing colonization of flood-prone areas and the massive loss of wetlands and natural floodwater retention in floodplains via dike construction and river straightening. Consequently (and obviously), urban inhabitants perceive river floods negatively, and the cultural relationships between humans and rivers are being lost [55] [11]. The River Culture Concept defines River Culture as a process of ‘learning from the river’ and ‘living in the rhythm of the waters’. The biocultural diversity and co-evolution of people and nature are used as means to understand dynamically changing social-ecological relations [56]. River Culture is based on the hypothesis that both non-human biota (animal and plant species) and human cultural activities in river-floodplain systems have been driven by similar evolutive processes – the flood pulse. Flooding is a driving force in nutrient cycling at the river-floodplain scale, and many floodplain organisms have adapted to its rhythms [28], by developing risk avoidance and resource use strategies in various ways. Animals and plants adapt their life cycles to the changing environment, and humans follow these patterns, e.g., seasonal agricultural practices in floodplains. Resource

use conflicts are seasonally interrupted by the wet/dry phase change, resulting in long-term strategies (non-human biota) and alternating rules for private properties and commons (humans). For cultural dimensions, the wet and dry cycle is identified as an impulse generator for various forms of art inspiration, aesthetics, music, religion, spirituality, etc. [11], [55], [57], [58]. Such river-bound biotic activities and social practices, i.e., the entity of all adaptations, traits, and strategies, are considered synoptically in River Culture, they should and need to be equally taken into account in NbS application while dealing with river floods, aiming at sustainable development in a growing urbanizing setting.

Specifically, River Culture Concept proposes five tenets: 1) Reset values and priorities in riverscape management in favor of human wellbeing and a harmonious coexistence of man and riverscape; 2) Live in the rhythm of the waters, i.e. adapt management options in accordance with the hydrological dynamics rather than fighting against them; 3) Transform traditional use of rivers into modern cultural activities and management options; 4) ‘Ecosystem bionics’: by copying survival strategies of flood-pulse adapted organisms novel forms of human use can be developed; 5) Make the catchment (river basin) the geographical base unit for all kinds of political decisions in landscape management [11]. The original version of the River Culture Concept does not particularly focus on types of riverine socio-ecosystems as the case with the Social Connectivity Concept [59]; instead, it deals with the relationship between humans and rivers in general. The focus on urban waters was later given in a comparative analysis of urban hydro systems in the Global South and North [8], [60] and in a concept of how human-river-encounter sites could be developed [54]. More recently, precise suggestions for stream daylighting, i.e., the return of fully canalized streams to the surface, were made [61]. These more application-oriented developments have a clear focus on the urban context.

COMPARISON BETWEEN NBS AND RIVER CULTURE CONCEPT

Responding to increasing biodiversity loss and climate change impacts, NbS and River Culture Concept both recognize the importance of restoring natural systems in favor of overall human-welling, and finally, achieving the objective of sustainability [11], [20]–[22], [62]. Focusing on riverscape, River Culture deems that natural floods set for biological and cultural diversity, and the cultural values for riverside communities have long been ignored [11]. It ‘re-defines’ the river identity by restoring/mimicking natural flows and re-adapting to it – learn from the experience of humans and non-human biota [11]. NbS underlines taking advantage of nature to address social challenges and can be implemented in various landscapes [21]. This approach was developed from a repository of local practices, and its evidence and knowledge base keep enriching [62]. As a think piece, River Culture Concept was formulated with an inductive approach with traditional, primarily indigenous, river management examples, then refined to the urban context and will need further applications in society to thrive. Apart from the epistemological difference, NbS and River Culture also face different challenges. Gaining growing popularity, NbS has been implemented worldwide, but universal guidance is still limited – although IUCN provides the first-ever set of benchmarks in 2020 [22]. Most NbS projects remain small-scale and site-specific, often facing financial shortages and scaling-up difficulties. River Culture is in a more theoretical stage; the feasibility of restoring biocultural diversity and the possible risks of learning from the traditions are based on expert opinion and global comparisons [63] rather than empirical evidence. Therefore, NbS offer opportunities for real-world practice to transform the River Culture Concept into action, and River Culture can complement NbS with a system perspective and environmental ethics, i.e., respect for natural floods (Tab. I & Fig. 2).

Table I. Comparison of the concepts of NbS and River Culture (based on [11], [20]–[22], [62])

| | NbS | River Culture Concept |
|------------|--|---|
| Respond to | <ul style="list-style-type: none"> • Climate change impacts • Biodiversity loss | <ul style="list-style-type: none"> • Climate change impacts • Biological and cultural diversity crisis in riverscapes |
| Background | <ul style="list-style-type: none"> • Increasing interest and recognition of the nature-related practice existing at local societies in science • Increasing policy discourse across the globe supports NbS’ deployment | <ul style="list-style-type: none"> • Research on flood pulse and natural flow regime • Growing studies of bio-cultural diversity and their interlinkages • Rivers have spiritual, religious, and cultural links with people • Many river restoration projects are engineering measures and solely address human needs |
| Scale | Physical features (river channel, floodplain and adjacent valley) in a river catchment | Riverscape as both a physical river corridor and a cultural space |

| | | |
|--------------------------------------|---|--|
| Objectives | <ul style="list-style-type: none"> • Long-term sustainability • Harmony between humans and nature | |
| Approaches in urban flood management | <ul style="list-style-type: none"> • Harness natural systems to help address societal challenges (eco-engineering) • A mix of large-scale (e.g., floodplains, lakes) and small-scale (e.g., green roofs, trees) interventions facilitating stormwater runoff • Multi- and/or seasonal use of flood-prone areas | <ul style="list-style-type: none"> • Living with floods, i.e., natural wet and dry cycle • Learn from adaptive strategies from both humans and non-human species • Respect and take advantage of the flood pulse • Retreat from flood-prone areas • Restore urban floodplains and blue-green corridors (if needed, by dilapidation) |
| Challenges | <ul style="list-style-type: none"> • Scale up the implementation • Implementation depends on available lands and resources • Short of financial resources • Conceptualization of many existing practices • Develop a coherent and universal guidance | <ul style="list-style-type: none"> • Increasing gaps (in terms of memory and connectedness to current cultural practices) between traditional ecological knowledge (and strategies by biota) and “modern life” • Change of values and beliefs • Selection and transformation of traditional practice into modern river management • Change the basic territorial unit of landscape management to the river basin |

Both NbS and River Culture develop a set of principles. River Culture Concept puts forward five tenets [11], IUCN proposed NbS’ 8 ‘global standards’ [22]. We derive nine common fundamental principles shared by the two concepts and unfold their different instructions (Fig. 2). The commonalities include: 1) Re-establish relationships between people and nature; 2) Make use of ecosystem services; 3) Deploy with economic feasibility; 4) Climate change adaptation and mitigation; 5) Enhance biodiversity; 6) Manage adaptively; 7) Align with local perspectives; 8) Adopt a landscape approach; 9) Balance trade-offs. The most significant overlap between concepts can be seen in the “design by nature” approach. In NbS principles, it primarily consists of mimicking or implementing physical structures that exist in nature and using them for adaptive measures, such as creating floodable space in cities. In River Culture Concept, the “landscape-scale bionic” tenet goes beyond this physical aspect, as it focusses explicitly on the entity of adaptive strategies by the biota such as migration along with the moving water level, and to develop flood-resistant survival structures, as they are known, e.g., from aquatic and terrestrial invertebrates [64] and how to integrate them into human adaptive strategies in flood-prone areas. Hence, the main differences identified between the two approaches are: Focusing more on implementation, NbS provide practical ideas for the designing process and mainstreaming. Considering environmental ethics in social-ecological interactions, in the River Culture Concept, rivers have the chance to develop human’s ethical care towards nature.

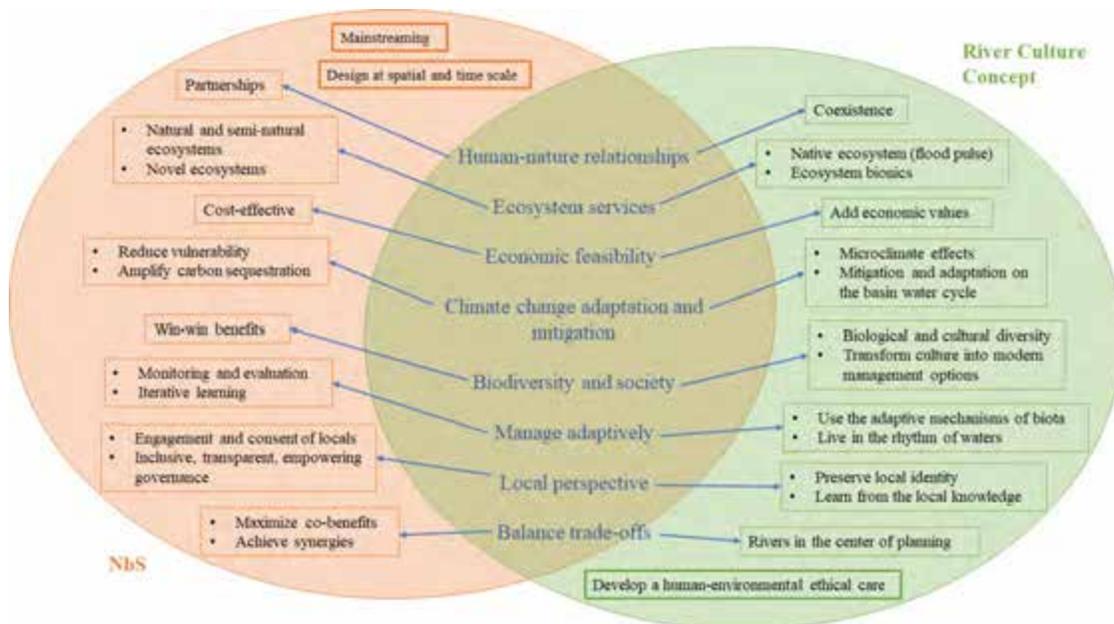


Figure 2. Comparison of the principles of NbS and River Culture Concept (based on [11], [21], [22], [62], [65]). Graph by Y. Cao.

EVALUATION FOR NBS PROJECTS WITH RIVER CULTURE TENETS

The River Culture tenets provide the rationale to review NbS from a River Culture perspective; we, therefore, create respective evaluation indicators for each tenet and complete an evaluation framework (Tab. II). The tool measures to what extent the NbS projects fulfil River Culture Concept and suggest how River Culture could improve them.

Table II. An assessment worksheet with evaluation indicators of each tenet of the River Culture Concept

| Evaluation criteria | Indicators |
|---|--|
| River Culture tenet 1) Reset values and priorities in riverscape management in favour of human wellbeing and harmonious coexistence of man and riverscape | <ul style="list-style-type: none"> • Does the project improve the water quality (i.e., measured with physical/chemical elements)? • Does the project restore habitats for biota? • Does the project preserve or enhance biodiversity in rivers and riverscapes (e.g., species richness)? • Does the project convey cultural-specific connotations of the communities, groups and individuals concerned (e.g., the name represents a local identity)? • Does the project apply a landscape approach (providing multiple land use, balancing competing land-use demands, sustainable land use)? • Does the project improve human health and wellbeing (i.e., physical, mental, and social health)? And in which way? |
| River Culture tenet 2) Live in the rhythm of the waters, i.e. adapt management options in accordance with the hydrological dynamics rather than fighting against them | <ul style="list-style-type: none"> • What is the level of flood protection? • Does the project restore the river's longitudinal connectivity of flow, sediment, and migratory biota (e.g., removing instream artificial barriers)? • Does the project restore the lateral connectivity between the river and the floodplain (e.g., by removing/degrading embankments, levees, floodwalls, etc.)? • Does the project implement environmental flows, i.e., does the project keep or restore pulse-shaped hydrology (e.g., annual flooding) in any type of natural water bodies? • Does the project provide opportunities for seasonal (cultural) activities? • Does the project promote new regulations in this regard, e.g., seasonal fishing moratoriums? • Does the project avoid construction in the floodable landscape? • Are there adaptative designs applied, e.g., permeable pavements, flood-adapted architecture? |
| River Culture tenet 3) Transform traditional use of rivers into modern cultural activities and management options | <ul style="list-style-type: none"> • Does the project maintain, eliminate, or modify tangible cultural heritage assets (e.g., remove/displace patrimony, reduce/offer space for cultural activities, restrain/eliminate the destructive activities, create new forms of festivals/events)? • Does the project safeguard/enhance the diversity of intangible river-related cultural expressions (e.g., reflect spiritual human-river-relationships)? • Does the project add economic values to the traditional use forms of the river resources (e.g., label the cultural products such as the European "appellation d'origine protégée" (AOP), attract real estate investment, enrich touristic attractions)? • Does the project provide environmental education (e.g., build museums, offer educational activities, invest in environmental research)? • Does the project initiate tourism development? If so, is it eco-tourism? |
| River Culture tenet 4) 'Ecosystem bionics': by copying survival strategies of flood-pulse adapted organisms novel forms of human use can be developed | <ul style="list-style-type: none"> • Does the project take advantage of the flood pulse (e.g., use of nutrients brought about by the floodwater, use of the flow to restore pioneer habitats and reset plant succession)? • Does the project use/mimic natural adaptive mechanisms, such as migratory behavior or flood resilience? • Does the project improve rivers' ecosystem services, i.e., supporting, regulating, provisioning, and cultural services? And in which way (e.g., use the ecological functions of floodplains, wetlands, and lakes designed for flood risk management)? |
| River Culture tenet 5) Make the catchment (river basin) the geographical base unit for all kinds of political decisions in landscape management | <ul style="list-style-type: none"> • Is the river in the center of land-use planning and management? • Does the project involve any cooperation crossing geographical or political scales? • Does the project facilitate a new governance structure (e.g., establish new authorities, adopt Integrated River Basin Management)? • Does the project integrate all river-concerned stakeholders (especially those profiting by and those paying environmental costs of river modification) by creating a 'bassin de responsabilité'? • Does the project enhance the rivers' functions on the catchment scale and hydrological cycle? • Does the project facilitate cultural exchange along the river? |

ASSESSMENT OF NBS EXAMPLES WITH A RIVER CULTURE PERSPECTIVE

Phoenix Lake, Dortmund, Germany

Located in Germany's historic industrial heartland of steel and mining, Ruhr area, Dortmund is a post-industrial city with more than 590,000 inhabitants and confronted challenges of social polarization, pollution, and absence of green and blue spaces after 150 years of industry development [66], [67]. The Dortmund Project (2000-2010, later extended until 2018) successfully transformed the city's industrial economy into a service and knowledge economy in the 21st century [68]. An artificial lake, the Phoenix Lake, was constructed in Phoenix East, a former industrial zone. With an average depth of 2.5 m and a surface area of 24 ha, Phoenix Lake contains 600,000 m³ of water with an additional flood protection volume of 235,000 m² [44]. The lake is located south of the Emscher River, a natural river turned into a 423 km underground concrete sewer in the early 20th century and daylighted from 1990 [61], [69]. The floodplain of the Emscher River was extended to 35m wide, where the river is adjacent to Phoenix Lake. As a result, the lake can mitigate Emscher's fluvial floods and is considered a NbS intervention. Phoenix Lake has good water quality in European standards [44] and supports high biodiversity, hosting 709 species of fauna and flora in 2014, including 12 endangered species [70]. However, the project also caused gentrification. High-quality housing, restaurants, cafés, bars, and parks around the lake have raised the real estate price in the lake region by over 1.5 times above the city average, working-class people rarely benefit from it, and low-income populations were marginalized [71]. Little employment opportunities were provided for low-skilled workers [68].

Sponge city, Wuhan, China

Wuhan is in the middle of China, has a population of 11.8 million and hundreds of rivers and lakes. However, with rapid urbanization, the total area of lakes in Wuhan has decreased sharply from 983.29 km² in 1973 to 647.47 km² in 2013 [72]. Rainwater drainage systems in Wuhan were referred to as the Soviet model in the 1950s with a low rate of conduit coverage and small diameter pipes that are easy to block during rainstorms [73]. With heavy rainfall events in summer (accounting for near 50% of the annual precipitation), the decreasing natural water storage capacity, and an antiquated drainage system, Wuhan is easily stroke by significant flooding events [72]. As a result, Wuhan was the first pilot city selected in China's Sponge City program in 2015. Sponge City is designed to absorb and restore rainwater during flood seasons and utilize it during dry seasons with various measures to replace grey infrastructure with green ones. It is considered a scaled-up NbS. Wuhan Sponge City (2016-2030) plan covers 38.5 km² with 389 separate projects. Mixed NbS interventions include restoring floodplains and transforming them into wetland parks (e.g., Wuhan Garden Expo Park, Wuhan's Yangtze River Beach Park), connecting six major lakes, and upgrading the city's basic infrastructure such as drainage systems and embankments. Vegetation, green roofs, rainwater tanks, permeable pavements, etc., have also been implemented in neighborhoods [74]. At the end of 2020, 20% of Wuhan's built-up area has been transformed into a 'sponge' (covered by green infrastructure), with a total area of 179 km². Furthermore, the percentage is expected to reach 80% in 2030 [75].

Cache la Poudre River Restoration Project, Fort Collins, Colorado, the U.S.A.

The Cache la Poudre River is a seasonal, snowmelt-driven river originating in the Rocky Mountains running east into the lower-elevation plains in Fort Collins, Colorado, the U.S.A. The river is an essential source of drinking water and stormwater conveyance; residents in Fort Collins also consider it embedded in community identity [76], [77]. However, dams and reservoirs were built to meet the growing water demands and induced hydrologic alteration of the river. Nearly 60% of its water is diverted out of the river for agricultural, municipal, and industrial uses. The floodplain was also severely damaged due to gravel mining and urbanization, destroying its ability to mitigate river floods [77]. The restoration of the Cache la Poudre River started in 2011 with initiatives of local stakeholders and has implemented a series of projects led by Fort Collins municipality to bring river flows back up to healthy levels. It is considered an NbS practice. Measures included removing the concrete, large debris, and fences along the river, lowering the riverbanks, deconstructing abandoned diversion structures, and creating riffles as fish habitat. Native plant communities were established in the riparian terrace, and a pond was widened up to form a wetland. Overflow channels were created to divert surface water back to the river for flood mitigation. Non-motorized activities were promoted with the 40-mile Poudre River Trail, connecting various parks and the Poudre River learning center [78].

Assessment results and comparison

Three NbS examples are analyzed based on the analytical tool with the River Culture evaluation tool (Tab. III). The assessment worksheet was used to evaluate each project's performance concerning River Culture Concept's five tenets. For each tenet, questions were answered with secondary data from books, academic journals, newspapers, websites, government records, etc. Table 3 summarized the results of the three examples and classified them into three aspects: 1) accordance with River Culture; and 2) improvement with combining River Culture (Tab. III).

Table III. Suggestion for improvement and comparison of three NbS examples with River Culture evaluation

| Examples | Accordance with River Culture | Suggestions based on River Culture |
|-----------------------------------|--|---|
| Phoenix Lake | <ul style="list-style-type: none"> • Create habitats for fauna and flora, maintain excellent water quality with aquatic plants acting as filters to bind nutrients, support high biodiversity • Provide high recreational use and facilitate economic transition • Transform remaining industrial factories into the historical heritage | <ul style="list-style-type: none"> • Use the lake to support the pulsing hydrology and seasonal fluctuating of the adjacent Emscher river, safeguard the lake’s water quality when receiving and retaining overflows from the river • Deprioritize business growth in lakeside planning, develop the ‘cultural linkages’ with the lake among lakeside communities, involves all relevant stakeholders (especially the low-skill workers) in decision-making, and prevent further gentrification • Integrate the lake’s function for micro-climate buffering into the larger task of mitigating climate change impacts |
| Wuhan City | <ul style="list-style-type: none"> • A scale-up NbS with hybrid flood protection measures (reinforce the riverbank, dredge, restore and connect lakes and rivers, upgrade plumbing and drainage systems, increase absorbent roads, etc.), natural floodplains are partly restored and multi-functioning as riverfront parks (e.g., Wuhan Yangtze Riverfront Park) • A holistic vision on urban water management: drainage network is designed connecting lakes and rivers to regulate water runoff systematically • Increasing blue and green spaces improve human wellbeing • Improve water quality with clean-up works, i.e., elimination of black odorous water bodies [79] • Safeguard an ‘intimacy’ with water in local culture by offering direct access to water and hosting riverside recreational activities • Raise public awareness with Changjiang (Yangtze) Civilization Museum • Mitigate climate change impacts with augmented carbon sequestration capacity | <ul style="list-style-type: none"> • Develop long-term monitoring, systematic assessments on biodiversity conditions and create a database • Prohibit direct water discharges into the rivers in the ‘drainage-river-lake network’ system, protect rivers’ ecological quality • Study the socio-economic consequences of the program, e.g., the influence on housing transaction prices [80] and gentrification • Take advantage of flood pulse to keep water levels in the restored wetlands • Put rivers at the center of Sponge City’s land-use planning, widely restore urban streams’ longitudinal (e.g., through dam removal) and lateral continuity (e.g., by demolishing concrete banks) • Strengthen upstream-downstream cooperation and coherent land-use planning on the catchment scale • Replace more grey infrastructures that are still dominant for flood defense • Displace human settlements that are located in the flood-prone areas • Regulate and/or restrict tourism and visiting in vulnerable wetland parks • Enable public communication and participation, promote public-private partnerships for funding resources |
| Cache la Poudre River Restoration | <ul style="list-style-type: none"> • Increase flood protection levels with the restoration of floodplains and their connectivity to the river by lowering riverbanks and elevated berms (artifacts of the mining operation), creating shallow wetlands, and revegetating the riparian area • Use flood pulse (overbank flooding, recharge and maintenance of alluvial groundwater levels, sediment scours and deposition) to create habitats and grow forests in the riparian terrace • The river corridor and floodplains are federally designated as National Heritage Area, providing a framework for the protection of the area’s natural and cultural environment • NGOs, universities, and local communities actively participate in the restoration process • Tourism develops with Poudre River Trail and parks, public fishing access, etc | <ul style="list-style-type: none"> • Safeguard the water quality in the river during wildfire and flash floods (identified as the highest priority threat to the river’s water quality) • Assess the ecological impacts of increasing recreational activities on restored areas (e.g., the paddle park – Poudre River Whitewater Park – that was built in 2019) • Restore the river’s longitudinal continuity by continuing removal of old dams, reject the new dam-building project (the proposed Glade Reservoir in the river as part of the Northern Integrated Supply Project) • Integrate the project into a larger task of mitigating climate change impacts |

DISCUSSION

The three NbS examples successfully mitigate urban floods in respective cities and provide economic and social co-benefits. They all reflect River Culture tenets in different ways. Nevertheless, specific suggestions to improve their long-term sustainability by complying with other River Culture tenets are made (Tab. III). The results also reveal some issues in current NbS urban flood management; we hereby discuss them in the following aspects.

Potential to improve NbS by integrating River Culture Concept

By employing green ‘infrastructures,’ NbS are eco-engineering measures that use ecology to predict, design, construct or restore, and manage ecosystems that integrate human society with its natural environment for the benefit of both [81]. In urban flood management, NbS often see rivers as waterways and exploit their social-ecological functions. Integrating River Culture Concept into NbS may help create the missing societal linkages between the novel ecosystems [82] and riverine communities, and reduce/balance trade-offs in the implementation process. Potential methods could include: 1) improve riverscape management in urban flood management by holistic urban planning and administrative process with greater local communities’ engagement and participation in designing and implementing NbS. At present, different NbS projects located at the rivers’ upstream and downstream are often site-specific and lack connectivity. And public participation process has been sometimes omitted in favor of implementation effectiveness. The “basin of responsibility” tenet of the River Culture Concept suggests including all stakeholders within one catchment into one political unit. All NbS projects within the river basin should also form a coherent network of blue-green infrastructures; 2) replace the ‘repairing attitude’ with the willingness to seriously implement natural structures in cities. Comprehensive behavioural adaptation to the pulsing hydrology is needed, this includes substantial dilapidation of constructed space in order to re-establish natural blue-green corridors [60]. In the current NbS, urban planning still considers floods in the first place as a nuisance to be fought rather than a process that is also beneficial. Besides, some water-retention parks are prohibited from entering in flood seasons, however, human activities (e.g., recreation) during dry seasons can have serious negative impacts on biodiversity; River Culture Concept makes use of flood pulse to not only create a unique habitat for native biodiversity but also restore a rhythmic pacemaker for human life, thus, attitudes and actions of environmental care should be developed [11], [57], [83]; 3) learn the adaptation strategies from non-human biota and from the local/traditional ‘water cultural practice’, tailor specific NbS measures to suit local conditions. At present, NbS are implemented in a wide range, many ‘copy-paste’ the techniques used in other cities. River Culture solutions also include the transformation of adaptive behavioral strategies from nature and from traditional communities into modern, sustainable management of rivers.

Potential to improve River Culture Concept by integrating NbS

In urban water management, the River Culture Concept orients people towards interacting with nature by recovering the connection between the city and its nearby rivers [8], [54]. NbS provides opportunities to realize such engagement with innovative approaches, i.e., using natural features and processes to tackle social challenges. The techniques of real-world NbS projects precisely correspond to the River Culture tenet 4) of ‘Ecosystem bionics’. Potential applications to improve River Culture by integrating NbS include: 1) the novel ecosystems that NbS create offer a lens to observe and study the new, co-evolving adaptive patterns of all living organisms in the River Culture Concept. By enabling new green urban commons in urban society, NbS, in turn, create additional space for new relations between people and nature as well as between people in their communities, i.e., forming the sense of place [84]; 2) the development of NbS research and considerable investment in NbS projects in managing world-wide river floods help embed River Culture Concept into the global task to tackle climate change, and create synergies among climate change mitigation and biocultural diversity conservation; 3) hands-on experience from NbS may continue to enrich River Culture tenets with inductive reasoning, emerging issues such as environmental justice (e.g., the equal distribution of benefits of urban biodiversity [85]) can be incorporated into the concept. In this sense, the popularity of the NbS approach can help to implement elements of River Culture for the mutual benefit of both approaches.

CONCLUSION

To respond to increasing urban flood risks under the increasing climate change impacts, integrated urban flood management that involves ecology, biodiversity, society, and economy, accompanied with an inclusive governance structure, is urgently needed. With the preservation of nature and the creation of co-benefits, NbS for urban flood management prove to be the way forward. Relying on flood pulse, the River Culture Concept underlines the adaptative strategies of all living beings living in

the riverscape and ‘live with the natural floods.’ Both approaches study the interactions between people and nature, which have been through a progressive decline in more urbanized societies [86], and span disciplines that are traditionally poorly connected. Acknowledging the mismatch and possible trade-offs between the outcomes for humans and nature [87] in NbS urban flood management under the present circumstances, we attempt to combine NbS and River Culture Concept, defining an evaluation tool based on River Culture tenets to assess NbS’ sustainability. Three NbS examples (Phoenix Lake, Wuhan Sponge City, Cache la Poudre River Restoration) are assessed, and specific recommendations are made from the River Culture’s perspective. The results show that NbS projects for urban flood management meet certain River Culture principles; however, many of the projects still have the potential to improve the human-river relationships by seeing rivers as social-ecological systems (not solely physical structures). Combining NbS and River Culture Concept broadens the application of sustainability science and contributes to the social-ecological transition process; we further conclude the following sustainability lessons: 1) humans and non-human biota equally share an adaptation strategy to the dynamic equilibria (i.e., floods) and should co-exist in a harmonious way in the city; 2) people should adjust behaviors to adapt to the rhythm of waters (e.g., retreat, explore seasonal resources); 3) cities could build climate resilience through redundant services delivered by river ecosystems no matter if they are irreplaceable, undervalued, or at risk; 4) involving the social-cultural connectedness (including psychological and spiritual aspects) of humans to rivers help re-shape human-nature relationships and shift the anthropocentric paradigm. In brief, we hope combining NbS and River Culture Concept will help advance the harmony between humans and nature.

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URBAN GREEN AND ITS VALUE FOR THE CITY: ECONOMIC VALUATION OF ECOSYSTEM SERVICES OF MULTIFUNCTIONAL GREEN WALLS IN AN URBAN CONTEXT

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ABSTRACT

Building resilient and liveable cities in times of increasing urbanisation and progressing climate change requires well-considered action towards sustainable urban development. Multifunctional green façade elements such as the VertiKKA (“Vertical Air Conditioning and Wastewater Treatment System”, combining a green living wall with façade photovoltaics and greywater management) can offer technical solutions to meet (some of) the urgent urban challenges. Besides high investment costs and marginal monetary benefits like reductions of incidental housing costs, VertiKKA provides several uncompensated public benefits including ecosystem services mainly originating from the green element. A valuation of the ecosystem services of VertiKKA provides arguments and evidence for the public benefits originating from a multifunctional green wall that are of relevance for citizens. Main ecosystem services, provided by the green VertiKKA module, are regulating services such as local climate and air quality regulation, carbon sequestration and reduction of heat island effects as well as cultural services including impacts on mental and physical health, aesthetic aspects and improvements of quality of life. Furthermore, it provides habitat for species and contributes to biodiversity. The present paper introduces valuation methods, designs valuation approaches for the VertiKKA and includes a holistic qualitative assessment of benefits as decision basis and road map for urban decision makers. Results show that urban green is of great value for cities with diverse positive effects on, inter alia, well-being, mental and physical health, air quality and microclimate, biodiversity and the urban image.

KEYWORDS

green walls, ecosystem services, value of urban green, economic valuation methods, VertiKKA

INTRODUCTION

In times of increasing urbanisation, constantly growing density of urban settlements and respective effects on city climate, resource consumption and quality of life, sustainable urban development is a crucial element to create liveable and resilient cities. Urban green and its ecosystem services attract increasing attention of urban planners as they have numerous positive effects on environment and citizens.

Cities with little green infrastructure often face a variety of problems that are intensified by the above mentioned developments, described e.g. by Kraus et al. [1] and Dettmar et al. [2]. Building materials like concrete and asphalt absorb energy in form of sunlight resulting in heated up buildings and streets. This leads to high air and surface temperatures. Traffic further decreases air quality by emitting exhaust fumes and particulate matter. Ventilation and air exchange is blocked by the density of relatively high buildings and therefore, hot and polluted air stays in the city. Rainfall can reduce the intensity of particulate matter in lower air layers but leads to another urban challenge: water retention. Due to a high degree of soil sealing, large water quantities have to be discharged by the sewage system and can cause floodings [3]. Further, citizens are exposed to negative influences that can be associated with too little urban green. Noise pollution reinforced by highly reflective concrete wall surfaces, for example, can lead to higher stress levels and related health issues [4]. The lack of recreational space, especially for children, and alienation from nature are additional problems. Taken together, these circumstances have significant impacts on the health of citizens.

Thus, urban green is not only of ecological importance but also of economic and social value for the city although these benefits are often unseen or underestimated by decision makers. As it is a main task of a city administration to provide a safe living environment, it is important to draw attention on the benefits of urban green, on its ecosystem services and its positive effects on the attractiveness of a city as well as the mental and physical health of its citizens. And as space is scarce in urban settlements, new, innovative and smart forms of urban greening are required.

The research project VertiKKA uses a technological approach to increase energy, land and resource efficiency and improve environmental quality as well as quality of life within a city. In collaboration with the City of Cologne (Germany), the project partners develop and analyse a multifunctional green façade element using domestic grey water for irrigation and producing energy with attached movable photovoltaic elements. VertiKKA is one of twelve inter- and transdisciplinary projects of the funding programme *RES:Z Ressourceneffiziente Stadtquartiere für die Zukunft* (Resource-efficient urban districts for the future) sponsored by the German Federal Ministry of Education and Research.

In the present paper, the multifunctional green wall VertiKKA and its ecosystem services will be introduced, followed by theoretical background on the methods for the valuation of ecosystem services. Further, qualitative results of the valuation of ecosystem services of the VertiKKA module and respective valuation strategies will be presented and discussed.

THEORETICAL BACKGROUND

VertiKKA and its ecosystem services

Ecosystem services can be defined as the “benefits that humans derive from nature” [5]. With relevance to a valuation, they can be divided into **providing, regulating and cultural services**. A further category are **habitat and supporting services**. These are the basis for the other ecosystem services, like e.g. the photosynthesis, but will not be valued as such but as part of the other categories [5,6]. Providing ecosystem services are all material and energy outputs of an ecosystem. Besides food and raw materials such as wood and fibres, this category also includes drinking water, energy or medical goods. Regulating ecosystem services consist of the natural processes that maintain the quality of air, soil and water and mitigate harmful processes such as extreme weather and diseases. Wetlands, for example, can be a natural alternative to sewage treatment plants as they filter pollutants and nutrients from water. Cultural ecosystem services refer to all non-material benefits that people receive from ecosystems. A lifestyle close to nature has notable positive impacts on mental health. Nature also has an important function as spiritual, recreational and leisure space. The attractiveness to tourists of a natural phenomenon, for example, would be a cultural ecosystem service [5].

VertiKKA is a vertical multifunctional façade element combining three main components: a green living wall, greywater recycling and photovoltaics. These components are linked and support each other: Greywater that is available in most buildings is used for irrigation of the plants. This not only provides water for the plants but further fertilises them, as nutrients are filtered

out by the substrate of the living wall. Movable photovoltaic modules can protect plants during extreme weather events while the plants lead to increased efficiency of the power generation through its temperature control function. Electricity production covers the energy demand of the greywater management. VertiKKA is still in the stage of development and can be seen as part of a new urban water management strategy by treating domestic greywater at source, see e.g. Middendorf et al. [7].

Figure 1 shows components, main synergetic effects and ecosystem services of the VertiKKA element.

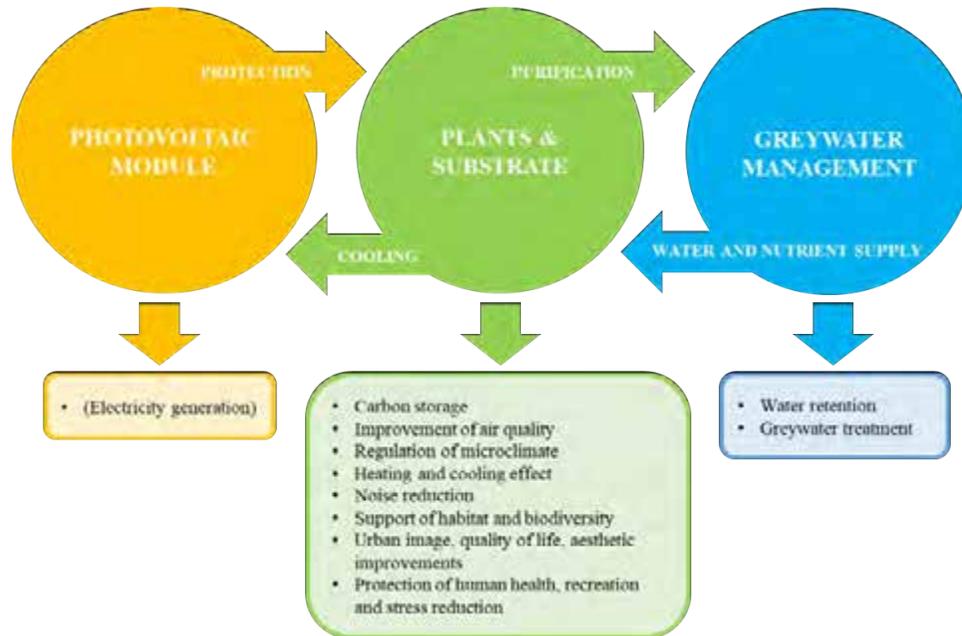


Figure 1 The VertiKKA components (own illustration)

The central component of the VertiKKA is a living wall system and most of the ecosystem services originate from the vertical green as can be seen in Figure 1. Plants provide ecosystem services by metabolizing nutrition from the greywater in the process of photosynthesis. By splitting the greenhouse gas carbon dioxide, the plant is producing oxygen and evaporation water, which cools the surrounding air while the generated biomass is a natural carbon sink. The leaves can absorb particulate matter from the air depending on its surface texture. They also provide habitats for small animals [8].

Besides those pure ecosystem services, the VertiKKA deploys combined services of ecosystem and technology. The microorganisms in the substrate ensure water purification that is enabled by an irrigation system. The whole greywater treatment has multiple positive effects: The purification of greywater allows a double usage causing not only a relief of the sewerage system but also a saving in freshwater demand while automatically supplying the plants with nutrients and water. Another combination of ecosystem and technical services is the better thermal performance of a building combined with a VertiKKA. Better insulation and shading in the summer can reduce energy consumption for heating and cooling [9,10,11]. The sound insulation inside the building can be improved while on façade with VertiKKA, sound waves reflect less and scatter more leading to a potential reduction of noise pollution in the streets.

The last purely technical service of the façade greening is provided by the photovoltaic modules mounted on movable slats on the outside of the VertiKKA to generate electricity and protect the plants from heavy rain, wind and frost. Although solar electricity generation is a technical task, it is positively influenced by the ecosystem service “cooling”. Efficiency of photovoltaic modules lowers with higher temperatures meaning the evaporating plants can increase the overall efficiency of the solar panels [12].

The valuation of ecosystem services

The valuation of ecosystem services comprises a combination of economic valuation methods, participatory approaches and secondary analyses [5,13]. It not only includes a monetary classification of the ecosystem services but also a holistic assessment of qualitative and quantitative benefits as decision basis and road map for urban decision makers.

In the following, main valuation methods and their fields of application will be presented shortly. The suitability of the different valuation methods depends on the kind of ecosystem service, the availability of data, desired results, possible efforts and local conditions.

Due to the tradability of providing ecosystem services like food, wood and fibre, the **market price method** is simple and well suited to value those easy to measure services (by amount or weight). Here, the market prices of provided goods will represent the value of the ecosystem service [13].

However, if there is no market price available or the service itself delivers no physical (tradable) output that can be quantified easily, this method cannot be used. That is the case for most regulating and cultural services. One example is the indoor cooling effect of the VertiKKA: The service itself cannot be traded on a market but technical solutions providing the same service (like air conditioning) can replace the service for a certain market price. The **alternative cost method** is based on this idea. The ecosystem service is quantified and a scenario is used where an alternative solution on the market provides the same performance. The calculated cost of the alternative solution is the counter value with which the ecosystem service is valued. In the VertiKKA example, it would be the price of air conditioning the living space with the same effect as the VertiKKA does. Basis of the assessment is the market price of the technical substitute or equivalent. The biggest challenge of this method is the quantification of regulating (and cultural) ecosystem services [13].

Another method with a monetary result is the **damage cost method**. It is suitable for all ecosystem services that provide some sort of a protection function. Basis of the valuation are the calculated costs to repair a potential damage or the (initial) cost of a destroyed object. In cities for example, the water retention capacity of urban green can be used to prevent floodings during extreme rain events and can be calculated by the damage costs of a flood. To quantify/monetarise protective effects of preventive measures on human well-being and health, it is necessary to assign a value to the human health itself, which is discussed controversially. The health damage cost method is very dependent on the valuation of human well-being and quantification of the denied harm. Research on precise, general and transferable values for both holds many challenges leading to a wide range of results. In 2011, the INTARESE and HEIMTSA projects as well as the WHO “Burden of Disease” study addressed this issue. The results show a wide range of values for human health. For example, the monetarised damages of a heart attack ranges from 2,200 to 32,000 Euro [14].

All methods presented to this point refer to utility values. Participatory approaches like the **willingness to pay analysis** differ from these approaches as the method can value non-utility values as well, for example a lake view. A result can be achieved by asking the affected citizens, what those ecosystem services are worth in their opinion. This can take place via questionnaires or in workshops. A similar but more differentiated method is the **choice experiment**. Different scenarios (e.g. façade with green living wall and a façade without) with different prices are presented to participants. Then, they are asked to select their benefit-maximising scenario. The predefined prices of the scenarios reduce the range of results. However, this method may not accurately reflect the opinion/willingness to pay of the citizens due to the predefined specifications [13].

The **hedonic pricing method** is an indirect valuation approach based on revealed preferences. Here, price differences are detected based on observations of objects, usually real estates that are almost identical but differ in the service considered. For example, the value of (green) recreational spaces close to real estates can be determined by comparing real estates with and without (direct) access to such spaces. The statistical evaluation of real estate prices and the resulting differences are the basis for the valuation [13,15].

The **travel cost method**, like the hedonic method, determines results based on an indirectly revealed willingness to pay via existing demand behaviours on the market. In this approach, the distance that visitors or customers travel to get to their desired place or service forms the basis of measurement. Therefore it is used in particular for mostly cultural ecosystem services that are relevant to recreation and tourism [13].

The **secondary analysis** (e.g. benefit transfer) attempts to transfer results from a suitable primary source to an ecosystem service under investigation. In theory, this method makes it possible to evaluate any ecosystem service, but in practice there is often a lack of robust and fitting primary research especially for this relatively new research topic [13]. The used primary source determines the scope of the valuation, e.g. regarding use of utility/non-utility values, suitability to assess a certain service and the range of results.

Table 1 gives an overview of the above described valuation methods, compares their concepts and gives information on their suitability. While the first three methods are based on actual prices in the market, the following four methods value the ecosystem service based on willingness to pay: The hedonic approach and the travel cost method **indirectly** via purchases made by individuals (**revealed**) and the choice or willingness to pay analysis **directly** via a survey (**stated**). As can be seen from the above, utility-based methods are based on monetary values, while non-utility-based approaches are able to also evaluate more abstract services such as aesthetics or biodiversity [13].

Table 1 Comparison of valuation methods

| Method | Based on | Utility based? | Best suited for | Range of results |
|--------------------|-----------------------------------|----------------|---------------------|------------------|
| Market price | Product price | yes | providing services | small |
| Alternative cost | Price for alternative | yes | regulating services | medium |
| Damage cost | Price of damage | yes | regulating services | wide |
| Travel cost method | Travel expenses | yes | cultural services | small |
| Hedonic pricing | Change in (real estate) prices | yes | cultural services | medium |
| Choice experiment | Price of scenario | no | regulating services | medium |
| Willingness to pay | Individual opinion | no | cultural services | wide |
| Benefit Transfer | Primary source (literature, etc.) | --- | --- | --- |

All introduced methods are able to provide monetary results in a setting with full information. But due to a lack of relevant data regarding many ecosystem services, results will not always be quantifiable, cannot always be adequately monetarised or may be very inaccurate containing a lot of estimations and approximations. For a holistic assessment, it is important to also include qualitative and quantitative results in the valuation of ecosystem services. The authors use the following approach to the valuation of the ecosystem services of the VertiKKA (Figure 2).

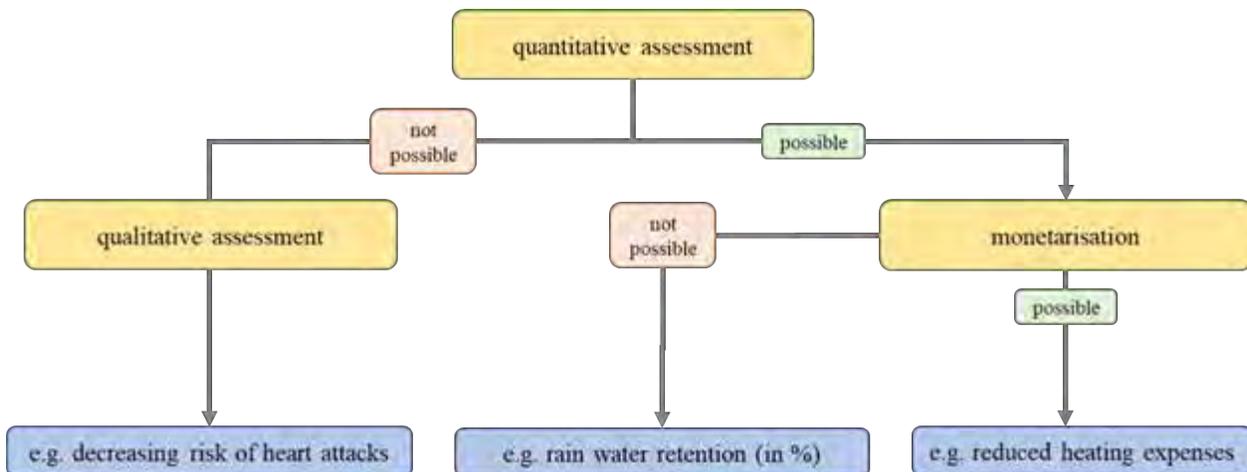


Figure 2 Valuation approach (own illustration)

The assessment bases on general studies on façade greening as well as direct project research on the VertiKKA. Literature research revealed information on the mode of action and the performance of different ecosystem services and previous similar valuation approaches. Interim results of the research project provide information on the operation and function of the VertiKKA and its potential performances.

RESULTS

The following chapter on results contains a qualitative description of the benefits of VertiKKA’s ecosystem services and describes different valuation approaches.

At this (early) stage of development of the VertiKKA solution, qualitative assessments are used particularly often for the valuation of the ecosystem services since data is only available to a limited extent and the qualitative presentation of the dimensions of the ecosystem services is in the foreground.

Heating and cooling effect

VertiKKA elements on the façade can improve indoor climatic conditions and the microclimate around the buildings [9-11]. These effects emerge from the three aspects:

1. The plants evaporate water on their leaf surface. The evaporation process needs energy and this leads to a cooling effect. This external effect of cooling by evaporation will be part of the section on microclimate.
2. The green living wall provides shade for the façade, the sunrays will be absorbed and reflected by the façade element and this reduces the cooling requirements of the interior.
3. VertiKKA lowers the heat transfer coefficient of the wall and thus has an insulation effect.

Simulations can approximate quantitative values for the indoor heating and cooling potential of the VertiKKA modules (see Alsaad/Voelker [9] and Alsaad et al. [10,11] for first results). The value of the in-house heating and cooling effect can be determined by calculating costs for alternative heating (e.g. gas) and cooling (e.g. air conditioning) options (method: alternative cost).

Greywater treatment

VertiKKA has a greywater treatment function. Greywater will flow through the substrate of the living wall that filters out nutrients and impurities. After this filtering process, the water can be used as process water e.g. for garden irrigation and toilet flush. The use of the greywater reduces the amount of waste water and can relieve the urban sewer (this will be analysed in the section on water retention). Further, the obtained process water can substitute fresh water and therefore reduces the fresh water demand [7].

The valuation of the greywater treatment service will be monetarised with avoided waste water costs and avoided fresh water costs. Avoided waste water comprises the amount of water that leaves the system via evaporation in addition to the amount of water that will be used twice as fresh water and, after filtration by the VertiKKA, as process water. Avoided fresh water represents the amount of water that can be substituted by the recycled greywater (method: market price).

Noise reduction

Noise reduction effects can emerge from sound reflection and absorption of the VertiKKA construction. Absorbing elements in densely built-up neighbourhoods lead to reductions in sound pressure. Further, the water content of the substrate positively influences the sound insulation. Literature on respective effects of living walls show a broad range of results (see e.g. Boos et al. [16] and Wong et al. [17]), but agree on the high potential for sound absorption.

The value of the noise reduction will be expressed in physical terms of sound pressure.

Sound insulation is no tradable good, therefore alternative prices need to be used for a monetarisation, e.g. prices for sound-insulating windows or other noise barriers. The need for sound insulation and its prices heavily depends on existing sound insulation measures as well as local noise pollution. The economic benefits of VertiKKA with regard to sound insulation can be expressed, for example, with the marginal costs for the next best or next cheapest noise protection measure (method: alternative costs).

Further, a hedonic valuation method could be used to determine a value for noise reducing effects of the VertiKKA by analysing the development of the affected real estate prices and directly linking price increases with differences in noise levels (like e.g. Preuss-Bayer [18]). This is a very complex procedure and as the VertiKKA is still in the development stage, such real estate prices are not available (method: hedonic pricing).

Another, also very complex approach is the determination of avoided costs for health care. The relationship between noise pollution, stress reactions and the resulting consequences for human health are well documented, especially with regard to cardiovascular diseases. The quantification of avoided health measures is a multifaceted approach with a high degree of insecurity (see e.g. Babisch [4] and Weyer [14]; method: damage cost).

Improvement of air quality

With VertiKKA, fine dust and pollutant content can be reduced and the oxygen content in the ambient air can be increased. Plants produce oxygen through photosynthesis and thus contribute to air quality. Low oxygen and high CO₂ concentrations trigger poor concentration and fatigue. Douglas [19] confirms the suitability of different plants to filter pollutants from the air.

Also, particulate matter can be bound by plants depending on their leaf surface [20].

The cleaning of the air from particulate matter can be pictured, for example, by quantifying the number of kilometres driven by a car that a certain surface area of VertiKKA can neutralise (based on average particulate matter emissions of cars and the leaf surface of the plants).

Cost of technical solutions for cleaning the air, like an air filter, could form the basis of an alternative cost valuation for this service (method: alternative cost).

Another approach is the determination of avoided costs for health care. Especially respiratory diseases are triggered by a poor air quality and constant pollution. A quantification in this field is a very multifaceted and complex undertaking (see e.g. Menke et al. [20]; method: damage cost).

Regulation of microclimate

In the case of the VertiKKA, the microclimate can be influenced by regulation of the ambient air temperature (cooling by vapourisation, as described in the section on heating and cooling) as well as radiant heat from heated objects. The green living wall also provides a potentially better performance than trees for the reduction of the heat island effect as treetops limit air exchange with higher (cleaner) layers of air, whereas vertical greening enables air exchange [2].

Studies prove that heat stress leads to increased health risks, e.g. by showing the connection between rising temperature and increased mortality of people over 65 years [21].

Sound approximations to real values regarding the influence of the VertiKKA on the surrounding microclimate can be made via simulations (e.g. ENVI-MET). A monetarisation is possible by determining costs for alternative investments that deliver similar benefits e.g. façade paint with colours that rise the albedo value of the surfaces or costs for alternative urban green with similar regulation functions (method: alternative cost).

Carbon storage

During the process of photosynthesis, carbon dioxide is absorbed from air and water, oxygen is again released to the air while carbon remains in the plant. Depending on their specific carbon binding capacity, plants function as carbon sinks.

The amount of stored carbon is calculated by the amount of biomass on the VertiKKA element and its carbon content. With a respective carbon dioxide-equivalent and the present carbon dioxide price (of the trading scheme), a monetarisation can be made (method: market price).

Water retention

The water retention capacity of the VertiKKA can lead to a discharge of the sewage system, which is especially relevant for heavy rain events in urban areas with a high degree of soil sealing [3].

Flood damages can be prevented and evaluated. The result is heavily dependent on local conditions of the sewage system, on the expected extent of damage as well as the defined framework of the assessment (method: damage cost). An alternative determination of a valuation could be the ratio of the amount of grey water retained to the amount of a heavy rain event. This can display the dimension of the flood prevention in case of a heavy rain event as it reveals the mitigation potential regarding the consequences of heavy rain. This approach does not use a classic valuation method but a special quantification putting the performance in context to the problem and thus creating better interpretability and comparability.

Support of habitat and biodiversity

The vertical greening offers habitat for smaller animals in the city, e.g. insects (bugs, spiders, butterflies), birds and sometimes even bats [8]. Further, it serves as so-called “footboard biotope” connecting other main habitats.

The value of this ecosystem service, i.e. the appreciation of this service can be evaluated by analysing the preferences of citizens: (1) surveys on willingness to pay (method: willingness to pay or choice experiment) or (2) the derivation of the willingness to pay by assessing the consumption of other products that “trade” appreciation of nature and/or animals, e.g. expenses for bird feeding (method: revealed preferences).

Protection of human health, recreation and stress reduction

Several studies describe the positive effect of the presence of plants on the mental and physical health of people (see e.g. White et al. [22] and Ulrich [23,24]).

A valorisation can be made based on a participatory approach, i.e. a survey on the willingness to pay for the presence of a green wall (method: willingness to pay or choice experiment). An alternative assessment method seems possible although very complex: Analogous to a study by Ulrich [24] a valorisation of damage costs could be designed. In his study, Ulrich found that for patients after standard hospital surgeries, having a room view on a green park (compared to a view on a brick wall) reduced the speed of recovery, increased well-being as well as reduced pain and sedative doses (method: damage cost).

Urban image, quality of life, aesthetic improvements

The influence of urban green on the cityscape is diverse. It can increase the identification with the city as well as the closeness to nature (with positive effects on health, as described above). An aesthetic design of infrastructure, e.g. façade greening, is even able to increase the willingness to pay: successful design often leads to overcompensation. Schloesser [25] found out in her study (surveying citizens of the city of Cologne, Germany) that a majority (range between 83-96 %) see a beautification of a building, street, neighbourhood and city through façade greening.

A valorisation can be made based on a survey (method: willingness to pay or choice experiment). The design of a hedonic pricing evaluation, where real estate prices (with and without VertiKKA or close to a VertiKKA and far away respectively) are compared, could be an alternative method after the launch of the VertiKKA elements (method: hedonic pricing).

Electricity generation

Electricity generation (from solar energy) is not a typical ecosystem service, but at it is a further benefit of the VertiKKA whose yields are favoured by the ecosystem services such as the evaporative cooling, it will be also considered at this point. It represents a borderline case of cooperation between nature and man-made technology. Here, the market price method can be used for valuation after the calculation of the electricity yield.

Summary

Figure 3 gives an overview of the above described ecosystem services and developed valuation approaches.

| | Service | Category | | | Valuation approach(es) |
|---------------------|---|-----------|------------|----------|---|
| | | Providing | Regulating | Cultural | |
| Ecosystem service | Protection of human health, recreation and stress reduction | | | x | willingness to pay/choice experiment damage cost |
| | Urban image, quality of life, aesthetic improvements | | | x | willingness to pay/choice experiment hedonic pricing |
| | Support of habitat and biodiversity | | | x | willingness to pay/choice experiment revealed preference |
| Combination of both | Carbon storage | | x | | market price |
| | Improvement of air quality | | x | | alternative cost damage cost |
| | Regulation of microclimate | | x | | alternative cost |
| | Heating and cooling effect | | x | | alternative cost |
| | Noise reduction | | | x | alternative cost hedonic pricing |
| | Greywater treatment | | | x | damage cost market price |
| | Water retention | | | x | damage cost |
| Technical solution | Electricity generation | x | | | market price |

Figure 3 Overview ecosystem services and potential valuation methods of the VertiKKA (own illustration)

DISCUSSION

The qualitative presentation of the results gives an overview of the diverse contributions and benefits of the ecosystem services coming from the VertiKKA and possible valuation strategies.

Insulation effects, greywater treatment and electricity generation can be estimated with low uncertainty and effort using market prices of suitable alternative or substitute products. Noise control, air filtration, water retention, microclimate regulation, urban nature as recreational space and positive psychological effects are the performances that are about protecting or improving human health.

The qualitative assessment reveals a high potential for the VertiKKA to reduce the risk of damages from noise, heat, flood, stress and air pollution. However, measuring and valorising the performance with the damage cost method requires complex simulations to accurately quantify cooling effects, sound insulation or air filtration performance. Results heavily depend on predefined parameters such as location and building type. And as results are very dependent on dimensioning, location and other environmental parameters, the potential for error and inaccuracy is very high, generalisation is not appropriate and transferability hardly given.

Further, the VertiKKA, as multifunctional green wall, incorporates several trade-offs and mutually exclusive optimal cases of the different components: The air-cleaning service, for example, is particularly useful in narrow and deep street canyons, whereas yields of the photovoltaic module would be higher on walls with far-reaching direct sunlight. The ecosystem services have different optimal conditions, so the site selection will always influence the performance.

In general, alternative cost approaches can be pursued for most of the ecosystem services. But here, the quality of valuation depends on an adequate selection of alternatives and it is not always possible to find an alternative that delivers similar services. Usually, the alternatives represent the underlying service differently, incompletely, better or worse, which limits the comparability. For example, an activated carbon filter could provide the air filtering effect of the leaf surfaces. The actual filter performance would probably be higher, but the way of archiving the performance would be completely different. The fans of the activated carbon filter generate noise and consume electricity. The filter itself has no aesthetic value and must eventually be disposed.

When it comes to monetarisation, the described utility value methods need exact and complex simulations for the provision of reliable values. An alternative way to generate a monetary value without the described quantifications is by means of a survey: The affected citizens themselves determine a value for the different ecosystem services according to their preferences and willingness to pay.

At this early stage of development of the VertiKKA but also in general, a qualitative valuation of the ecosystem services seems to be an appropriate methodology supporting the goal of increasing the awareness and appreciation for ecosystem services, especially for urban green. A holistic qualitative assessment of benefits provides multiple arguments and a broad decision basis for urban planners and decision makers. A quantification can underline the qualitative statements. A monetarisation should only be the method of choice in cases with access to adequate information (e.g. via market prices).

Landsberg et al. [26] examine increasing importance of the integration of ecosystem services into performance measurements to draw a more comprehensive and realistic picture of “a project’s immediate and long-term impacts”. Especially in the case of the VertiKKA, it is important to portray the various ecosystem services and uncompensated benefits for an urban neighbourhood, as the economic performance is considerably low (high investment costs and low expected revenues) due to the multifunctional character and the combination of the different sophisticated and costly components.

The overall objective of the VertiKKA is to contribute to urban sustainable development (see e.g. Middendorf et al. [7]). Here, the valuation of its ecosystem services can play a crucial role in the performance assessment and can highlight its contribution to a liveable, resilient city.

In general, the valuation of ecosystem services offers the chance to emphasize the importance and the value of nature for humans. However, it should be pointed out at this point that an economic valuation (monetarisation) also harbours the risk of conveying the possibility of substituting natural capital with man-made (financial) capital. This would not support the idea of sustainable development, where natural capital stocks need to be conserved to protect future preferences. However, the valuation of ecosystem services draws attention on the uncompensated public benefits of urban technologies and urban green respectively.

CONCLUSIONS

Assuming the reversibility of the negative effects resulting from missing urban nature presented in the introduction by increasing urban green, façade greening seems to be a particularly well suited concept.

Multifunctional concepts even more alleviate the challenge of limited available space in urban areas using yet unused areas for urban green and making new potentials accessible by combining other components. On the other side, multifunctional concepts require a high level of coordination and may incorporate trade-offs and mutually exclusive optimal functions.

The assessment of the ecosystem services of the VertiKKA disclosed a wide range of potential benefits, mainly originating from the green element, the living wall. Urban green positively influences, inter alia, well-being, mental and physical health, air quality and microclimate, biodiversity and the urban image. In a next step, a quantification of the ecosystem services of the VertiKKA and the application of selected valuation methods can be addressed.

Since most of the ecosystem services addressed are externalities, the benefits not only accrue to the building owners or residents, but also to the neighbourhood. Thus, most services are not relevant for the investment calculation since they do not lead to any direct payments. The owner of the VertiKKA usually gets no compensation for the described positive external effects. A valuation could lead to a compensation, e.g. through public subsidies or neighbourhood participation. The valuation is an expression of the appreciation for urban green and delivers various arguments for urban decision makers to support and advance its promotion.

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^a See e.g. information on the German emission trading system: https://www.dehst.de/EN/national-emissions-trading/national-emissions-trading_node.html;jsessionid=B60791499E535B4C5BBDE774A084EDD1.1_cid292 [accessed January 2022]

^b “Sustainable development is development that meets the needs of the present without comprising the ability of future generations to meet their own needs” (Brundtland report [27])

INFLUENT PARAMETERS ON THE EARLY BIOCOLONIZATION OF CEMENTITIOUS MATERIALS IN SEAWATER

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ABSTRACT

The main cause of biodiversity loss is human artificialization on natural environment (IPBES 2019). In marine area, with 39,400 km² of coastal and marine areas already encroached and an increasing demand of infrastructures to support human activities due to the growing of population, projected to reach 9 billion by 2050, it is clear that humanity needs to find ways to prevent its pressure on biodiversity. To this end, since the 1990s the “ecological reconciliation” concept has been trying to develop a win-win approach that unites ecological engineering with civil engineering. Today, civil engineers have a responsibility to incorporate eco-design processes in all construction projects, to ensure common benefits both for humans and for the ecosystems. Then, the new challenge of the 21st century is to develop eco-designed concretes that, in addition to their usual properties, provide improved bioreceptivity in order to enhance marine biodiversity. The aim of this study is to clarify the potential release of polluting elements from cementitious materials in seawater and to master and classify the intrinsic parameters that influence the biocolonization of cementitious materials in the marine environment. By using biofilm-culture-method (biofilm quantification), this study shows that the surface treatment with green formwork oil enhance the biocolonization whereas the application of curing agent has the opposite effect. The use of rough surface or slag cement CEM III increases the bioreceptivity of cementitious materials in the marine environment. Among the influent parameters, surface roughness proved to be the factor that promotes biocolonization most effectively.

KEYWORDS

Cementitious materials, Marine environment, Eco-design, Biocolonization

INTRODUCTION

In the marine environment, microbial cells are often found in complex, surface-attached communities, known as biofilms. By definition, biofilms are assemblages of single or multiple microbial populations irreversibly attached to a substrate or an interface and included in a coating of extracellular polymeric substances (EPS) [1]. Biofilms harbor considerable microbial diversity. Bacteria, archaea, algae, fungi, protozoa and viruses all form important components of the biofilm matrix and dominate biogeochemical and bioremediation processes in seawater [2,3]. Then, biofilms contribute to the biodiversity and ecosystem processes of aquatic ecosystems.

Moreover, any surface in the marine environment will be colonized with micro- and macro- organisms leading to biofilm formation [4]. This biocolonization process develops via four distinct phases; adsorption of dissolved organic molecules, attachment of bacterial cells, attachment of unicellular eukaryotes and attachment of larvae and spores [5]. Bacterial attachment is a highly controlled and regulated process whereby attached cells produce EPS to form structured and complex matrixes [6]. Then, these pioneer microorganisms facilitate the establishment of the next arrivals, including heterotrophic and photosynthetic microorganisms such as cyanobacteria, fungi, diatoms, barnacles, algae and protozoa [7].

However, in alignment with the global attention to environmental protection and biodiversity restoration in the marine environment [8], the number of studies about the biocolonization of submerged materials and their effects on marine ecology and biodiversity has increased in the last decade. Indeed, in the marine environment, urban, coastal and offshore structures provide an important protective function, but can also have unintended ecological consequences, such as the loss or modification of habitat and the alteration of hydrological and ecological flows [9,10]. The new challenge of the 21st century for managers is to eco-design marine infrastructure in a way that minimizes its ecological impact and increases its bioreceptivity (the ability to be colonized by living organisms) in order to enhance marine biodiversity without losing the structure durability [11].

Knowing that concrete is one of the materials most widely used for the construction of marine infrastructure such as ports and coastal defenses [12], cementitious materials have a negative image with regard to environmental pollution. Depending on its chemical composition, a cementitious material may contain substances that promote or inhibit the development of microorganisms by the presence of some heavy metals, in sufficient quantity in the cement [14]. Trace metal contamination in marine coastal areas is a worldwide threat for aquatic communities and a multi-chemical contamination influence both marine biofilm communities' structure and functioning [22].

Some studies assess that transport of drinking water via pipelines composed of cement mortar is not detrimental for health according to the European Union (EU, 98/83/CE) and the World Health Organization (WHO) recommendations. Moreover, concrete matrices are complex and possess the capacity to store trace toxic metals [23] and to stabilize heavy metals [24,25], even in marine environment [26].

Leaching tests are used to study the durability of concrete in aggressive environments but few studies deal with the environmental impact of immersed concrete. In 1996, SERCLERAT performed semi-dynamic tests on CEM I concretes and highlighted that heavy metals are almost undetectable in leachate water, even using cements spiked to 1000 - 2000 mg / kg [27]. In 1999, HILLIER *et al.* are also studying the leaching of toxic heavy metals by trace in CEM I concretes by integrating a longer exposure time of 254 days into deionized water. Based on the results of studies from the 1990s [28], he confirms that heavy metals are undetectable even at very low thresholds [29]. Then, the normative leaching tests do not make it possible to follow and quantify the releases of heavy metals.

The use of deionized water results in slow dissolution of hydration products (portlandite, ettringite and C-S-H), so that heavy metal leaching from concrete is sustained [30]. Therefore, the pH has always been a real issue in leaching. Then, some scientists are studying leaching phenomena at constant pH [31] and advise to know in what form the metals will be present [32] since some elements are only soluble in a pH range [27].

Only one study establishes conclusions on a significant absence of metal leaching into seawater [33]. This lack of study in seawater is relative to the difficulty to analyze the leachate in a strong ionic activity. No differences were noticed between Portland cement and slag cement concretes, a very low heavy metals release is measured. In the natural environment, measures are not relevant because the infinite rate of dilution.

On top of the material impact on the environment, cementitious materials are colonized after immersion in seawater. The intrinsic parameters that influence the bioreceptivity of cementitious materials in the marine environment are crucial and constitute a fundamental step towards more green and eco-designed marine artificial structures.

Generally speaking, the intrinsic parameters that influence the biocolonization (biofilm formation) of cementitious materials are the nature and the physicochemical properties of the surface: chemical composition, roughness, porosity, hydrophobicity and pH [13–19]. However, these factors are less well known in the marine environment. We showed in a previous study that the bacterial colonization of cementitious materials in seawater is influenced by the pH and the type of cement [20,21].

In order to help engineers in their new challenge of designing marine infrastructures using eco- designed concrete, the main objective of this present study is to determine the effect of two products which are widely used during concrete production on the biocolonization of cementitious materials in the marine environment. These products are the curing compound and the green formwork oil. Moreover, in order to select the parameter that promotes biocolonization most effectively, we also tested in this study the effect of surface roughness and type of cement. In addition, this paper proposes a short-term preliminary study to evaluate the potential release of heavy metals from mortar to deionized water and conclude on the environmental impact of the cementitious materials immersed into seawater.

MATERIALS AND METHODS

Preparation of Mortar Specimens

Ordinary Portland Cement (OPC) CEM I cement 52.5 N CE CP2 NF “SB” (provided by Ciments Calcia) and blastfurnace slag cement CEM III (composed of 60% ground granulated blast- furnace slag NF EN 15167-1, provided by ECOCEM (CAS no.: 65996-69-2) were used in this study to produce six types of mortar specimens (Table I). The mortar had a water/cement ratio (w/c) of 0.5 and was composed of 450 g cement and 1350 g sand (sand 0/4 EN 196-1).

Table I. Types and compositions of mortar specimens

| Mortar Specimen | Surface Type | Cement | CEM I (g) | CEM III (g) | Water (g) | Sand (g) | Curing Agent | Formwork Oil | |
|-------------------|--------------|-------------|-----------|-------------|-----------|----------|--------------|--------------|---|
| Control mortar | Ref | Smooth (SS) | CEM I | 450 | 0 | 225 | 1350 | - | - |
| Cured mortar | CM | | CEM I | 450 | 0 | 225 | 1350 | + | - |
| Oiled mortar | OM1 | Rough (RS) | CEM I | 450 | 0 | 225 | 1350 | - | + |
| | OM3 | | CEM III | 180 | 270 | 225 | 1350 | - | + |
| Biomimetic mortar | BM1 | Rough (RS) | CEM I | 450 | 0 | 225 | 1350 | - | - |
| | BM3 | | CEM III | 180 | 270 | 225 | 1350 | - | - |

After mixing, the mortars were cast in cylindrical molds measuring 2.7 cm in diameter and 2.9 cm high. After 24 h of hardening, the mortar specimens were removed from the molds and placed in a laboratory room at 20 °C for 30 days. Formwork oil (vegetable oil, BIODEM SI 3) was spread on the molds, using absorbent paper to avoid any surplus, before the mortar was poured. Curing compound (SikaCem®Cure) was added to the top of the specimens in accordance with the supplier’s instructions 1 h after stripping. The rough mortars were prepared with a rough silicone skin; no release agent was needed. The cylindrical molds filled with mortar were poured on the silicone skin and held in place with a weight.

Immersion conditions

An immersion test in seawater was carried out using flat-bottomed basins (polyester, 6 m long, 0.6 m high and 2 m wide) located at the IFREMER station (biology of exploited marine organism's research unit in Palavas, France). The basins featured a seawater inlet and outlet allowing for an open seawater circuit. To ensure that the experiment would be completed smoothly and avoid contamination of any type, the basins were cleaned before the cementitious material specimens were placed in them.

Quantification of bacterial colonization

Quantification of the bacterial biofilm adhered to the surface of the mortar specimens was performed using the protocol described by Hayek *et al.*, (culture-based methods) [20]. This quantification was carried out after 0, 1, 2, 6, 8, 15, 24, 26 and 28 days of immersion in seawater. After each incubation period, three specimens of each mortar type were placed in three sterile tubes containing 10 mL of sterile seawater. Bacteria adhering to the mortar surface were detached by immersing the tubes in an ultrasonic bath (Bandelin SONOREX™) for 10 min at 20 °C. The solution obtained was diluted using sterile seawater and 100 µl of diluted solution were spread on plates containing marine agar (MA, Dutscher, 490614). The plates were then incubated at 20 °C, and a colony count was performed at least 72 h after incubation. The results are expressed as colony-forming units per cm³ of mortar (CFU/cm³).

Statistical analyses

In order to evaluate the significance of the various biocolonization obtained, statistical analysis was performed using GraphPad Prism 5 (GraphPad Software, San Diego, CA, USA) and one- way ANOVA tests. Statistical significance was accepted by p-value <0.05 obtained using Bonferroni or Tukey's multiple comparison post hoc tests.

Contaminant release evaluation

To assess whether inorganic contaminants have been leached from the cements, the concentration of copper and lead was measured in the water. All dishes were previously washed with a solution of HNO₃ at 2N. A 4 cm square cube piece of mortars have been placed under slight agitation (30 rpm - rotation per minute) in deionized water at 20 ° C. A solid-liquid ratio of 1:8 was observed in this test. After leaching, 20 ml of samples were filtered using a 0.45 µm filter. Then the pH of sample was adjusted to 2 using 1N nitric acid before ICP-AES analysis. The detection limit for our method is 10 µg/L.

RESULTS AND DISCUSSION

The biological colonization of cementitious materials is affected according to the literature by many factors, including the environmental conditions, the bacterial properties and the physical/chemical characteristics of the material surface [16,34]. To avoid the effect of the environmental conditions and bacterial parameters on the biocolonization results, the mortar specimens were incubated at the same time under the same environmental conditions in the presence of the same marine bacteria. Therefore, only the physicochemical properties of the mortar surfaces could generate a different rate of bacterial colonization.

Effect of the curing compound and the green formwork oil on the biocolonization of mortar specimens

Generally, the curing compound and the green formwork oil are used during manufacturing to improve the durability of concrete; the curing agent is a liquid applied to the concrete or mortar surface to protect the material from water evaporation and give it greater aesthetic and mechanical durability, preventing early-age surface cracking [35]. Formwork oil is a mold-release agent that is applied to a wall of a mold to ensure easy separation of the hardened concrete from the mold by reducing the adhesion forces at the concrete/mold interface [36]. This oil forms a well-adsorbed and stable "lubricant monolayer" on the surface of cementitious materials, leading to improved release performance [37].

The effect of these two products (curing compound and green formwork oil) is poorly understood to date. Figure 1 shows that the curing compound inhibits the bacterial colonization of mortar submerged in seawater whereas green formwork oil has the opposite effect.

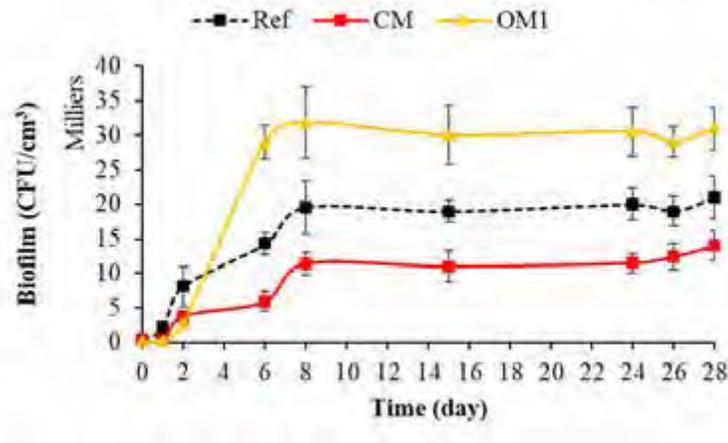


Figure 1. Quantification of bacterial colonization of mortar specimens. Each quantification was performed in triplicate using the culture-based method, and the error bars present the standard deviation from the values obtained. Ref = control mortar; CM = cured mortar; OMI = oiled mortar prepared with CEM I.

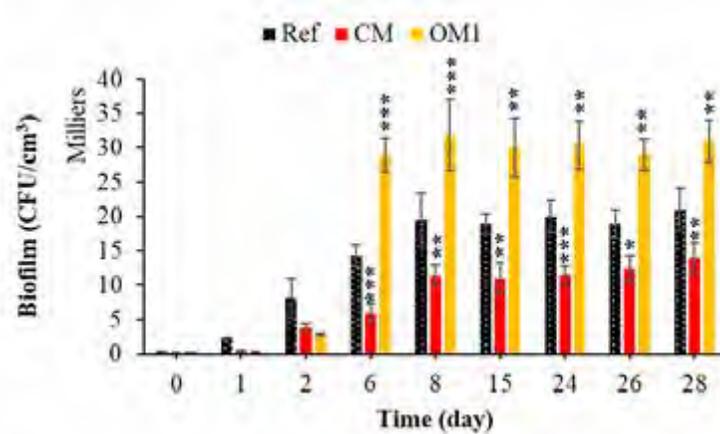


Figure 2. Statistical comparison (GraphPad Prism 5) of the biocolonization of mortar surfaces treated and untreated with curing compound or green formwork oil. Each experiment was performed in triplicate, and the error bars present the standard deviation of the values obtained. The experiments highlighted with asterisks differed significantly from the control (Bonferroni; **: $p < 0.01$, ***: $p < 0.001$) at the indicated time.

Figure 1 shows that the bacterial colonization of mortar surfaces started with a latency phase, followed by a phase of cell growth and accumulation on the surfaces and ending with a plateau phase. These colonization kinetics were also observed in most of the studies quantifying bacterial-biofilm formation on cementitious-material surfaces or on other surface types [19,20].

Figure 2 shows that the curing compound significantly inhibits the bacterial colonization of mortar submerged in seawater. Cells accumulated and grew faster and more extensively on an untreated surface. The compositions of curing compound used in this study indicate the presence of alkyl (C14-C18) bis (2-hydroxyethyl) amine, 5-chloro-2-methyl-2H-isothiazol-3-one and 2-methyl-2H-isothiazol-3-one (FDS Sikacem cure). These elements or their derivatives have been cited as anti-biofilm molecules that inhibited the formation and the accumulation of bacterial biofilm [38,39]. Moreover, the treatment of the material by a hydrophobic surface coating is cited as one of the anti-biofilm strategies used to inhibit bacterial and other organisms adhesion on the surface [40–42]. To verify the effect of the curing film on the hydrophobicity of the mortar surface, the contact angle with a drop of water was measured for the treated and untreated surface using a drop-shape scanner. From

their preparation until the start of the immersion test, the mortars treated with the curing compound presented a contact angle greater than 110° (40° in the case of untreated mortars), indicating a hydrophobic surface [43]. After immersion and under the action of seawater, the contact angle gradually decreased with time and became equal to that of the control mortar at 28 days of immersion (data not shown). Therefore, we propose that the curing compound inhibited the biological colonization of mortar surfaces in seawater because of its chemical composition (anti-biofilm) and its effect on surface hydrophobicity.

However, Figure 2 shows that the formwork oil significantly promotes the bacterial colonization of mortar submerged in seawater. The composition of the green formwork oil used in this study is not given. Detailed information is given neither in the technical product information nor in the bibliography. Therefore, knowing that green formwork oil is biodegradable, we propose that this oil applied on the surface of the mortar specimens was used as a carbon source by marine bacteria, according to the study and the results of [44,45]. Dusane et al. showed by a laboratory test that the biofilm formation is affected by the carbon sources. Lactic acid, erythritol, glycerol, glucose and edible oils increase this process [46]. Therefore, we propose that the surface treatment with this type of formwork oil increased the biological colonization of cementitious materials in the marine environment because it is used as a nutrients source by marine microorganisms.

Effect of the type of cement and the surface roughness on the biocolonization of mortar specimens

In order to compare and classify the intrinsic parameters that influence the biocolonization of cementitious materials in the marine environment, we also tested in this study under the same conditions the effect of the type of cement (the use of CEM III) and the surface roughness on the biofilm formation at the surface of mortar specimens.

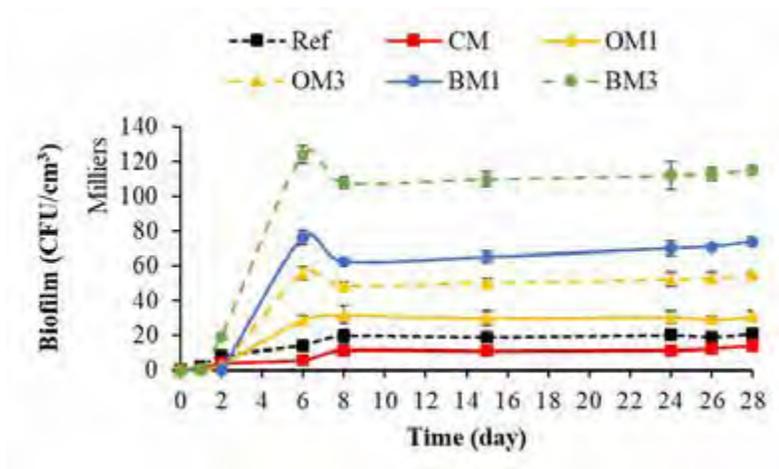


Figure 3. Quantification of bacterial-biofilm formation on mortar specimens. Each quantification was performed in triplicate using the culture-based method, and the error bars present the standard deviation from the values obtained. Ref = control mortar; CM = cured mortar; OM1 = oiled mortar prepared with CEM I; OM3 = oiled mortar prepared with CEM III; BM1 = biomimetic mortar prepared with CEM I; BM3 = biomimetic mortar prepared with CEM III.

Figure 3 shows that the bacterial colonization of mortar surfaces in the case of OM3, BM1 and BM3 has the same kinetic observed in the case of Ref, CM and OM1 (cf. Figure 1). However, the formation of bacterial biofilm was much greater in the case of CEM III mortars, regardless of the surface topography (BM1 vs. BM3) or whether formwork oil (OM1 vs. OM3) was applied. These results were in keeping with the literature, in which a similar effect of cement type on the biological colonization of cementitious materials has been reported [20,47,48]. In addition, a rough mortar surface significantly increased bacterial colonization in comparison with a smooth surface (Ref). This influence of surface roughness was identified in several studies concerning the biological colonization of cementitious materials [19,47].

Therefore, based on the rate of biological colonization (Figure 3), the mortar types can be classified from less to more bioreceptive in the following order: $CM < Ref < OM1 < OM3 < BM1 < BM3$. Then, the intrinsic parameters that promote the biocolonization of cementitious materials in the marine environment can be classified from more to less effectively in the following order: surface roughness > the use of CEM III (type of cement) > surface treatment with green formwork oil.

However, the main cause of concrete structure deterioration in the marine environment is the chemical attack caused by seawater ions such as chloride and magnesium sulfate attack [49]. According to the literature, the biological colonization of immersed concrete structure can have a protective effect (bioprotection) against chemical attack in seawater, leading to improved structure durability [50,51]; the marine organisms adhered to the concrete surface form a physical barrier that reduces surface permeability. The decrease in surface permeability leads to less-efficient diffusion of aggressive ions (Cl^- , Mg^{2+} and OH^-), which can increase the durability of a concrete structure in the marine environment. Furthermore, Lv et al. demonstrate that the presence of the *Crassostrea gigas* coating (biological coating) on the surface of marine concrete can reduce the water absorption of concrete, and enhance the resistance of concrete to chloride penetration and carbonation [52]. Then, improving the biological colonization of concrete structure in the marine environment can have a positive effect both for the environment (biodiversity restoration) and for the concrete structure (bioprotection).

Contaminant release from mortars to seawater

The obtained results show us that no copper detection occurs in all samples. The presence of lead neither can be affirmed since the measured concentrations are within the tolerances related to the measurement uncertainties (0.01 mg/L). These results are consistent with those of previous studies [29,33] which obtained concentrations is in the order of a few $\mu\text{g} / \text{L}$.

CONCLUSIONS

Eco-design of marine constructions is a major focus for researchers and construction companies working in marine environment, to enhance durability and also, since few years, to minimize and mitigate human impacts toward “no net loss” on biodiversity policies [18]. This study tests, compares and classify the intrinsic parameters that influence the biocolonization of cementitious materials in the marine environment. Regarding the parameters tested in the present work, we can summarize that: (i) Work practices such as the use of a curing agent and/or formwork oil have an impact on biocolonization; the surface treatment with green formwork oil enhance the biocolonization whereas the application of curing agent has the opposite effect. (ii) The use of rough surface or slag cement CEM III increases the bioreceptivity of cementitious materials. (iii) Among the parameters examined, surface roughness proved to be the factor that promotes biocolonization most effectively.

This study also concludes that no release of toxic heavy metals was detected during the leaching test in water. Further experiments need to be done using a leaching test in seawater even if the ICP measurement will be complex because of the significant ionic activity of sea water. More precise equipment ICP-MS would be relevant to possibly detect any heavy metals release.

These results could be taken up in future recommendations to enable engineers to design with the same level of knowledge both technical and ecological concerns, to eco-design marine infrastructure and develop real “win-win” projects.

ACKNOWLEDGMENT

The authors thank Emmanuel Rezzouk and Sébastien Triplet (IFREMER, Biology Research Unit for exploited marine organisms) for their welcome at the Palavas-les-Flots oceanographic station and thank LIB industry for the supply of the silicone matrix and their assistance. The authors thank NTNU, IMT Mines Alès and University Montpellier 3 for their participation or support and in particular Hugo Fahy and Thierry Vincent.

FUNDING SOURCES

This work was supported by the IMT Mines Ales.

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REGENERATIVE URBANISM – A SYNOPSIS: INVENTING THE PLATFORM FOR SUSTAINABILITY SUCCESS

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ABSTRACT

This paper describes humanity's sustainability predicament and the new approach needed over the 10-15 years remaining to reverse course and accomplish key milestones. It identifies a promising response emerging from innovation occurring across our planning, designing, and building practices at this moment of global environmental, economic, and social reckoning: *strategic regenerative systems sustainability* or *regenerative urbanism*. Three cases illustrate the approach and suggest the district as the best strategic scale. Descriptions of its characteristics enable recognition, understanding, and use. Initiatives pursue certifications such as Living Community Challenge, EcoDistricts, and LEED-ND, which are society's most evolved codifications of regenerative sustainability and urbanism. This response is a work in progress that requires global recognition, acceleration, and scaling. It is the beacon for 21st century urbanism being the antidote for our dual climate and sustainability challenges. The built environment-economy connection reveals how regenerative urbanism could catalyze the only complete solution; that is, the transition to a circular ecological global economy of inclusive prosperity within one generation for 9 billion people by 2050 and up to 12 billion by 2100. That solution would simultaneously mitigate climate change, establish the economic basis for inclusive prosperity, and defend against the extreme economic conditions that will intensify during the 100-year-or-more period of climate recalibration. As a bonus, solving the climate crisis with regenerative systems sustainability would cost no more than the climate solution itself and would create the only basis for climate cooperation. Regenerative urbanism creates a compelling value proposition and role for planning and design professionals.

KEYWORDS

Regenerative, Planning, Design, Ecological, Development, Urban, Region, Climate, Sustainability

INTRODUCTION

Humanity faces a dilemma after our 30-year sustainability response since the Earth Summit launched sustainability onto the world stage in 1992 (the UN Conference on Environment & Development, Rio, Brazil). We appear to be winning battles but losing the war. Is our current approach successful if it only slows the rate of natural systems destruction and the pollution of our economic and social systems? Does it allow us to mitigate climate change in time (the most visible challenge), and also address sustainability's more fundamental challenge: creating an economy that does not destroy itself and nature while ensuring a viable future for all? If not, what must we do differently?

The paper begins with an introduction to the dilemma, challenge, and emerging response of strategic regenerative systems sustainability and urbanism (referred to in this paper as *regenerative urbanism*). It then presents three cases that illustrate different approaches. The final two sections describe the principles, imperatives, and core concepts useful as the basis for wider recognition, use, and advancing this new whole systems practice.

Humanity's predicament is that our current approach is ineffective and failing—and most importantly, time is running out. We need decision makers at society's "levers" of sustainability with an accurate understanding of the challenge and the means to address it. The goal of this paper is to be one starting point.

The root of the problem is humanity's piece-meal greening approach to sustainability. It simply reduces the magnitude of incremental impacts, but total impacts continue to increase albeit at a slower rate. It does not reverse the accumulating destruction. More fundamentally, humanity's response focuses on making sustainable components of the system (buildings, cars, energy, consumption, etc.) not on making systems sustainability. Thus, our current approach is incapable of producing sustainability. The sustainability we need is systems sustainability, not simply "environmental friendliness," or components that are "less bad." Sustainability is a system "state," not a continuum of "badness" and "goodness" with an acceptable zone in the middle. A system is either sustainable or it is not.

The urgency demonstrated in the Intergovernmental Panel on Climate Change's (IPCC) recent AR6 Report^a and the current phase of the rural-urban transition underlines the need for regenerative sustainability and urbanism. The IPCC estimates a closing window of opportunity with only 10-20 years remaining for humanity to respond effectively to climate change: weaning the global economy off fossil fuel and fully transitioning to a renewable energy economy, mostly solar. However, not included in the IPCC report is the need to accomplish climate mitigation in the context of (1) adding two billion more people to the planet (2000-2050), (2) providing everyone with sufficient resources, and (3) accommodating more people in urban areas. About 68% of the global population will live in urban areas by 2050, up from 46% in 2000 and 55% in 2020 (the urban transition from rural to urban settlements).

Much of that growth will reside in cities and neighborhoods that have yet to be planned, designed, and developed, with the main question being will we develop regenerative or traditional degenerative cities? We cannot develop traditionally because that method is part of the larger approach that has brought the world to the brink of the stark reality of climate change and unsustainability. Thus, we only have one option for success: inventing and producing regenerative global city-region economies. But what would this option entail and how do we accomplish it in time?

Regenerative urbanism uses the integrated processes of living systems (its principles of planning, design, and economic policy) to produce the urban and regional systems innovation and performance needed for success. This approach includes shifting from our current economy's linear "take, make, waste" metabolism to one of a circular urban-regional metabolism. Such innovation adds more total value than total cost while accounting for externalities (costs typically left out of decisions over whether, how, and how much to produce). It creates better urban neighborhoods and districts that are attractive and healthy places compared to those that traditional development produces. However, and more importantly, it is also a new program and framework for innovation & investment. This program will produce a circular ecological economy with tenfold greater production capacity and the inclusive prosperity required to support a global population of 9 billion by 2050 and up to 12 billion by 2100 with only positive environmental impacts. It would fully mitigate climate change by creating a circular ecological economy that would not violate the regenerative life support principles of nature. Thus, it would not deplete living systems with its production processes. It would reduce GHG emissions quickly enough to limit global warming to the "red-zone" maximum of 1.5C degrees or less. This program is the minimum "design brief" for climate and sustainability success required to reverse accelerating cataclysmic climate change and unsustainability trends more generally, thereby creating the long-stalled promise of development around the world.

In summary, society's new regenerative urbanism planning and design brief would accomplish the following:

- restore damaged nature (the natural capital assets of regenerative life support processes),
- reverse climate change in time and re-establish the relatively benign pre-1990 climate conditions,
- expand human AND natural system productivity (carrying capacity) to the point of inclusive prosperity (for a global population of 9B by 2050 and 12B by 2100).

Fortunately, this solution does not need to be invented anew. It is arising from innovation occurring across the planning, design, and building professions around the world. However, society must nurture, advance, accelerate, and scale it quickly enough to achieve global sustainability success. It holds the promise of substantially expanding the carrying capacity of the human economy and biosphere. Tactically, this approach would allow us to harden the economy and society now. Doing so is an essential defensive economic move in response to climate change with or without mitigation success. It would allow us to maintain and expand economic production during the 100-300 years of the climate system's slow recalibration to pre-1990 conditions if mitigation is successful, or for increasingly hostile conditions if mitigation is unsuccessful. Extreme environmental conditions will make economic production increasingly difficult and costly, and could even slow or reverse economic growth.

It is this integrative regenerative systems sustainability approach to the built environment and economic activity that is required for success. Leading and advancing it is the new role and larger value proposition for professional planners, designers, and urban, regional, and economic policy makers. Creating regenerative built environments (both new and existing) also creates a core component of the needed regenerative economy, which in turn is a primary catalyst for system-wide sustainability. No longer is the built environment providing a simple shelter function with aesthetic or transportation and economic efficiency value. The built environment delivers substantial economic value as a core component of sustainability performance (or unsustainability). It stimulates (or prevents) moves to economy-wide sustainability. The need for and capacity to deliver that value is unprecedented historically, and crucial for global society's survival.

Furthermore, regenerative urbanism is likely the only antidote to climate change that can command the full global attention and collaboration needed for success, from people to world leaders and from the developed to the developing world. This is true because the real solution for climate change is not "simply" GHG emissions reduction. Success requires achieving that reduction by also creating a global economy of perpetual inclusive prosperity within one generation or sooner for a growing population. That economy and its urban and regional spatial configuration (built environment) would not simultaneously self-destruct and destroy nature. This is the "win/win" move. In the face of our current challenges, there are no win/lose moves remaining. We all survive and thrive or suffer and perish. The day of ecological, economic, and social reckoning has arrived. We have only a small window of opportunity to unite the leaders and people of the world in a massive Marshall-type plan for a regenerative global economy (i.e., the Plan that reconstructed Europe after World War II). The key component of success is the spatial configurations of regenerative urbanism (built environment), whose processes create, maintain, and enhance regenerative human systems sustainability for perpetual inclusive prosperity.

The discussion of the three cases reveals the principles and concepts of regenerative urbanism in action. The Kashiwa case reveals the potential to invent new governance entities for systems sustainability entrepreneurship. The San Francisco case shows how one can respond with existing tools, services, budgets, and planned investments to create regenerative instead of degenerative districts. The Portland Albina Neighborhood case illuminates how regenerative urbanism can build community capacity for both climate change resiliency and restorative justice in disadvantaged communities.

Call to Action

This paper proposes embracing the emerging regenerative systems sustainability approach as the necessary guide for 21st century sustainability and urbanism. It is the only antidote to climate change because it eliminates GHG emissions by correcting a self-destructing economy and associated destruction of nature (our irreplaceable regenerative life support system) and replacing it with one of inclusive prosperity. However, only the first chapter of that guidebook has been written. It is enough to begin quickly and then we can write the rest of it as we invent the balance of the approach in practice. Realizing our regenerative approach's potential given its incipient state will require that we recognize the innovation, understand it, and advance its use quickly in practice with the education, research, innovation needed for sustainability success in time.

This synopsis illuminates key characteristics for that purpose. The emerging approach of regenerative sustainability and urbanism described poses a question to us all: what can and should each of us do to secure climate and sustainability success? The answer is to integrate this knowledge into our lives, economic decisions, political support, and activism. For planning and design professionals, a few additional steps are clear. They are our call to action: *learn, make the market, deliver the value*. Please join ZGF Architects and the Sustainability 2030 Institute in contributing to an effective and powerful community. That growing community is trying to advance strategic regenerative systems sustainability and urbanism at the scale and speed needed for sustainability success in time (ZGF Architects and the Sustainability 2030 Institute).

THREE CASES

The three cases in Kashiwa Japan, San Francisco California USA, and Portland Oregon USA are instructive. They illustrate three different approaches to regenerative urbanism (respectively: governance, infrastructure, and equity). They work at the district scale to shift the built environment and economy from a degenerative to regenerative systems state. These projects are pursuing certifications such as the Living Community Challenge, EcoDistricts, the C-40 Climate Program, and LEED ND. They illuminate the necessary characteristics for 21st century urbanism being the only antidote to the dual challenges of accelerating climate change and unsustainability.

Kashiwa, Japan -- Urban Design Centers for Systems Sustainability

The Kashiwa Smart City^e in Chiba Prefecture, Japan, 18 miles north of Tokyo, is an example of a district that began in 2008 as an innovative focused transit-oriented development plan that evolved into a comprehensive transformational plan. It shifted focus to address the core planning challenges underlying the transit function, such as an aging community, population decline, economic shocks, and resilience. It became a powerful expansive plan to create a district capable of tackling the local dimension of national social, economic, and resiliency challenges. Innovation included a new governance approach with its Urban Design Center (UDC): a new business, government, and academic coordinating entity working with the community to shape the built environment and manage district-wide sustainability. This can be seen as an example of creating the new urban development capacity of sustainability systems entrepreneurship required to build sustainable communities.

Establishing the Urban Design Center Kashiwa-no-ha (UDCK) in November 2006 was the first step in implementing the Kashiwa-no-ha International Campus Town Initiative in March 2008. The initiative describes its objective as follows: “. . . to realize an international academic city in which cutting-edge knowledge, industry, and culture can be developed and bring about a next-generational environmental city where people coexist in harmony with a rich natural environment and healthy, high-quality living and working environments in a creative setting that integrates the campus and town through partnerships among the government, private industry, and academia.”

This transformed district has become the largest smart city to earn a LEED ND Plan Platinum rating. Its deployment of energy, water, and material use building strategies along with strategic urban design decisions has changed the mix of uses in the area. It changed how rainwater is reused and how the natural environment provides settings for business and community activities in a network of outdoor spaces that unify the district. The Kashiwa project creates a resilient 111-acre/45-hectare district that aims to resolve social, environmental, and economic issues common to existing global cities. Through the effective use of real-time technology and data delivery, Kashiwa-no-ha Smart City connects residents to each other and to the built environment, enabling them to make the best choices for themselves to increase comfort and productivity and for their environment to eliminate pollution, use solar energy, water, and other resources efficiently.



Figure 1. Model of Kashiwa-no-ha Smart City Plan, ZGF/Nikken Sekkei- Photo/design Aqua Terrace, Nikken Sekkei.

Kashiwa’s economic, sustainability-focused governance innovation of the UDC is rapidly expanding across Japan as a powerful new vehicle to cultivate built environments that form new settings for sustainable living. “Urban Design Center (UDC) is defined as new community-building organizations and hubs that go beyond the conventional framework of administrative urban design and community building; in UDC, various local community groups collaborate with one another, while urban design professionals also take part from an objective standpoint. Empirical research on UDCs is being conducted in conjunction with developing a network throughout the country.”

In Kashiwa, the powerful innovation of UDCK has transformed project goals. One project began as a conversation about the need for a regional water detention basin and expanded into a multi-use civic space called The Aqua Terrace. Another UDCK innovation created site and building performance guidelines that specified how individual buildings and open spaces could be configured to meet not only local and prefectural goals, but also to achieve national sustainability priorities and systems sustainability. This expansive planning canvas is atypical of traditional planning, yet it is required to address the complexity and needs of 21st century urbanism and sustainability.

San Francisco, California, USA—District Foundation for Regenerative Urbanism

In 2017, as part of its city sustainability program, San Francisco Planning conducted a small pilot test of regenerative sustainability and urbanism.⁴ SF Planning conducted the Regenerative City Assessment to consider the potential value of using a regenerative urbanism approach in the Central SoMa Area Plan for a rapidly developing mixed-use district. The pilot study assessed the performance of a regenerative approach against the traditional environmental sustainability proposals already developed in the Draft Area Plan. The regenerative approach developed four integrated system-wide components that comprise the infrastructural foundation for producing regenerative systems performance district wide.

1. Installing *district water and heat/cooling exchange* infrastructure to reuse existing water and energy that would be lost otherwise.
2. Developing an *system of blue-green, biophilic city infrastructure* to create a high-value, -health, -performance human community and natural environment that both mitigates and defends against global warming.
3. *Connecting and integrating the built environment across scales* (district, building, occupant) required to easily share resources and costs for a more efficient lower cost circular metabolism, built environment, and economy.
4. Developing *integrative metabolic centers* for circular material, water, and energy treatment and production.

Preliminary testing of these regenerative sustainability system planning and design concepts suggests that regenerative design and infrastructure may cost roughly 10 percent more than traditional development but yield approximately 50 percent more value. This order-of-magnitude estimate indicates that benefit likely exceeds cost. In addition to offering critical climate benefits, the investment would create more attractive places that people want and need: vibrant, vital, attractive, engaging, healthy places in our urbanizing world.

Though in a different context, the Central SoMa Regenerative City Assessment discovered the same need for a new governance entity as the case of Kashiwa. A new “district- or city-sustainability-developer-champion” actor is needed to assume responsibility for producing the full regenerative system performance of a district or city. This new governance entity enables working across the sectors, scales, and phases of development beyond what any one partner could accomplish alone. It also stretches across the on-going innovation in planning, designing, financing, building, and management required to overcome the many barriers to sustainability and to create regenerative urbanism. This approach would integrate government, private, and civic functions in new partnerships to create the capacity for producing regenerative urbanism. This coordination is essential for securing, increasing, and optimizing the multiple benefits and success that regenerative urbanism can produce.



Figure 2. Concept for a regenerative community, Regensia/ZGF

Portland, Oregon, USA—Regenerative Urbanism for Restorative Justice

The Oregon Department of Transportation’s (ODOT) Independent Highway Cover Assessment of the I-5 Rose Quarter Improvement Project in Portland Oregon combined the project objective of covering a section of Interstate 5 in downtown Portland with the residents’ goal of regenerating community in the historically disinvested area once divided by the freeway, Portland’s Historic Black Albina Community.^e

The project team sought to understand stakeholder interests, formulate potential highway cover scenarios, and assess their impacts and benefits. Engagement occurred through a series of virtual work sessions, surveys, and online public comments. It helped the project team understand how the highway cover could best be configured to create the greatest potential for restorative justice outcomes for the Black Historic Albina community: creating a diverse, inclusive, and accessible neighborhood. The heart of Albina—and project location--was a commercial, institutional and social spine for the community.

Historically, the walkable neighborhood was dominated by small-scale streets and community services were distributed throughout. The cover project design can provide the physical basis for restoring the area as a crossroads to and from Black community land uses, its institutions, churches, community centers, places of work and living. This neighborhood is the location of burgeoning activity led by members of Portland’s Black community. It can serve as one part of a larger community effort to reestablish Lower Albina as a center of Black identity and culture in Portland. The project concept is to create a highway cover that can support the Black community’s desire for self-determination and structure it so the Black community can build it, own it, and benefit from it into the future. This project proposed using a new governing entity, like the UDCK in Kashiwa, with land use decision-making and development authority over all aspects of the project. With this governance entity, the community shall reconfigure the built environment and its economy to improve community wealth, health, and cohesion for themselves.



Figure 3. Regenerative District , Albina Neighborhood, ODOT/ZGF

PRINCIPLES & IMPERATIVES

Understanding the principles and imperatives of regenerative systems sustainability and urbanism is essential for understanding how to achieve sustainability success and why our current approach is the problem.^f The imperatives of systems sustainability define the needed performance. Taking a strategic approach allows us to understand the gap between current reality and the needed future state. This design problem in turn becomes the frame for sustainability plans and projects project decisions at the smallest scale of urban development that support larger scale outcomes for the planet. Our current economic processes are based on principles and imperatives that destroy nature, its products, its species, its natural capital, and its regenerative life support capacity. Without understanding this point, we are surprised that we produce such results. During the 20th century, the “footprint” of human impact has expanded from the local to regional to global scale. Similarly, the risk of failure has expanded from city to region to the whole global economy and nature. For the first time in human history, we now face planetary life support system insecurity, and ultimately, destruction if we do not reverse trends.

There is no better and legitimate rationale for market policy intervention than the ultimate market failure we now face. The policy intervention would replace the existing degenerative principles and imperatives at the heart of our economy, society, and legal system with a new set of regenerative ones. These new regenerative principles and imperatives do not replace existing planning goals; they are added as the highest-level context. They are a new set of first-order system-design goals that produce the sustainability systems within which all other activity can occur without destroying our economy and nature. They define the needed performance of local projects or plans so they produce systems sustainability, not simply smaller incremental impacts.

On this point of system design, it is important to note that the defining difference between the twin climate change and sustainability challenge compared to all other challenges humanity has faced. That difference is the challenge of systems design, not individual component design. This challenge of designing systems context is new. Society does not yet have those skills, procedures, and expertise. Society has little if any experience designing systems, from the economy to community to culture to society. Typically, we take context (government, economy, laws, etc.) as given, and design the parts within those systems (e.g., the built environment). Thus, we need to invent the new systems design capacity for our professional practices. The shift to using sustainability systems performance imperatives instead of traditional planning goals is the way to specify, require, and achieve whole systems sustainability. Ultimately, this shift would reverse current trends and create global life-support system security and inclusive prosperity.

The primary regenerative systems sustainability imperatives include:

- No net destruction of nature (natural capital) -- only enhancement
- Renewable energy economy (100% solar and wind)
- Continuous cycling of all materials by design for deconstruction and materials reuse
- No pollution – no waste – by design (materials and process of a circular metabolism)
- Only organic food production (plant and animal)
- Open biological economic loops for material cycling in nature that are not toxic or otherwise harmful
- Closed technical economic loops for toxic materials harmful to natural systems (only temporary)
- Decisions based on full-cost accounting that includes externalities
- Land use and built environment performance that reinforces regenerative systems sustainability.

There are other regenerative systems performance imperatives. However, this list illustrates how they define the field of action within which activity can occur without destroying the human economy or nature. In the first instance, they are a set of system design and planning guidelines and regulations. However, they would depend on a higher-order set of laws and policy to support a beneficial system change. Continuous innovation in technology, guidelines, regulations, policy, and laws is needed and used to achieve regenerative systems sustainability performance and then to expand productivity (the system's "carrying capacity"). No matter at which scale one is working, even down to the smallest component of an urban space, these principles inform the design and functioning of the component to produce only net positive economic, environmental, and social *systems* sustainability.

CORE CONCEPTS

This final section introduces the primary concepts operative in a strategic regenerative systems approach to sustainability practice, or regenerative urbanism. Formulating a systematic methodology for practice is an upcoming task and will use these concepts as a foundation and starting point. However, the ideas described in this section should be sufficient for practitioners to recognize the emerging approach, and then learn it, begin practicing it, or accelerate use of it in one's existing practice. The applications will be different depending on scale, sector, jurisdiction, but the ideas will be the same.

Redefine Sustainability

One key characteristic of regenerative sustainability and urbanism is redefining sustainability around biological regeneration instead of incremental environmental impact reduction. Such a redefinition connects the human economy and society to the biosphere's living systems at the foundational level of operating principles. This definitional shift illuminates the many necessary shifts in sustainability practice as shown in Table 1, principally: from components to the system, from environment to economy, from problem solving to future designing.

Table I: Shifts in Practice When Regeneration is the Core Principle of Sustainability

| | |
|---|---|
| From stocks TO processes | From static parts TO dynamic systems |
| From linear TO circular material flows | From the environment TO the economy |
| From non-renewable TO renewable energy | From buildings TO city-region systems |
| From subsystem TO whole system optimization | From topical goals TO systems imperatives |
| From content TO context | From economies oblivious to the environment TO economies using regenerative principles |
| From symptoms TO sources of problems | |
| From impact reduction TO impact elimination | From problem solving TO future designing |
| From net negative TO net positive impact | |

Embrace the Emerging Innovation

Fortunately, we do not need to invent a new approach. It is emerging from the spontaneous innovation arising across our planning, design, and building professions over the past 10-15 years in particular. It is responding to the challenges of accelerating climate change and unsustainability and to the limits of traditional design and environmentalism extended to sustainability practice. It is a new regenerative, *living systems* approach to sustainability. It has the potential for success before time runs out over the next 10-20 years. Understanding this potential is essential. Simply put, regenerative urbanism is urban development that “makes” more than it “takes.” Regenerative city-regions of inclusive prosperity are the necessary innovation required to scale sustainability to the level of environmental, economic, and social health performance needed for success. Pioneers include EcoCity Builders, The Natural Step, the International Living Future Institute, EcoDistricts, the Biophilic Cities Network, Climate Positive Development (C-40), the World Resources Institute, the Systems Change Lab, the American Institute of Architects, and the American Planning Association.

Our professions’ leading-edge sustainability initiatives are forging and applying the principles of regenerative urbanism as follows.

- **Planning:** formulating the policies and rules for designing and building high-performance regenerative settlements and places (Eco-Districts, Eco-Cities, Eco-Regions).
- **Urban design:** adding water and habitat (biophilia) to the urban design palette to create high-performance regenerative living places with the urban metabolism of living systems.
- **Architecture:** shifting to energy efficient buildings that enable the renewable energy economy; using biophilia to create healthy living open spaces, places, buildings, walls, and roofs.
- **Landscape Architecture:** shifting from aesthetics to habitat creation for biodiversity and human health in living city-regions with the use of biophilic planning and design.
- **Utilities:** expanding from gray to include green urban infrastructure with nature-based solutions and ecosystem-services to create living urban and regional metabolism.

Scaling regenerative systems sustainability and urbanism to a formal global practice, or “main-streaming” it, will require recognizing, understanding, mastering, and advancing it with innovative practice. Over the past 10+ years, the center of innovation for sustainability has shifted from the academy to cities as the following examples illustrate.

- Burnaby, BC: *Full strategic integration planning for a regenerative city*
- Vancouver, BC: *100 percent renewable energy supply for stationary and mobile uses*
- Sydney: *Net positive water reuse*
- Amsterdam: *Circular local economic development*
- Shanghai: *Public realm vertical farming systems*
- Kashiwa, Japan: *New governance & smart regenerative city development*
- Vienna, Helsinki, and Palo Alto: *Automobile-eliminating emissions-free transit*
- Singapore: *Integrating wild nature into the city with biophilic city planning and design*
- Chicago: *Managing urban development to achieve health for all*
- Copenhagen: *Redevelopment for the regenerative city*

Begin at the District Scale

The three cases discussed above suggest the district as the best strategic scale for delivering regenerative urbanism. The EcoDistricts Movement uses a community's districts as the starting point for sustainability initiatives. Districts are locally defined sub-city areas of land use function and community identity, such as a residential neighborhood or a mixed-use district. Districts are the scale where people live and work. It is also the scale where most of the physical change is implemented and seen. It is the scale where citizen support can be best galvanized because the benefits are visible. Yet, delivering sustainability requires policy and planning at every spatial scale and across sectors and jurisdictions. For instance, attempting to share water or energy use across parcel lot lines and buildings to improve efficiency requires regulatory changes at the city, county, state levels and/or private utilities. In some cases, the district may also be the scale for efficient service delivery. For these reasons, the district can be considered the strategic scale of sustainability practice—a starting point to formulate the comprehensive cross-scale, -jurisdiction, and -sector solutions. The place to build understanding and support.

Start Now—Make the Market

As professionals and decision makers, we can begin practicing regenerative urbanism now, without waiting until it is fully formed. In doing so, we advance its development by using existing regenerative technology and planning services for all maintenance, repair, and replacement decisions faced in municipal or private operations and in planning for renewal and growth. However, to do so, we need to know that it exists for purchase in the market as a routine practice, not as a risky leading-edge innovation. Thus, policy leaders need to inform themselves and professional practitioners need to make the market for this new practice, which is not yet fully formed or functioning, and which is one of the current barriers. We can pay for regenerative urbanism with existing budgets, already planned investments, or by including it in upcoming budgets. We can begin easily and quickly by simply purchasing the regenerative instead of the degenerative option, thereby shifting our built environments' performance from degenerative to regenerative.

Lead with the New Value

Regenerative urbanism proposes a new value proposition (economic, environmental, and equity success), and therefore presents professionals with a new leadership role. They can use the new approach to configure the built environment to not only create great places, but to generate the systems sustainability performance and the productivity needed to mitigate climate change, eliminate poverty, restore nature, and expand the human economy for inclusive prosperity. Thus, regenerative urbanism extends beyond the traditional scope of land use to the economics, resource flows, and other urban, societal, and environmental systems that create system sustainability performance.

Shift to Regenerative Urbanism

A strategic regenerative systems approach is critical for sustainability success.⁸ It defines the field of the problem as the gap between needed performance and the performance of current reality, not simply between current reality and performance viewed as acceptable and attainable under current conditions (practical, feasible, political, technological, budget). Doing so addresses the whole problem which needs a complete solution, not simply the easy partial one.

If a regenerative systems sustainability approach is the answer, how do we do it? Shifting to it is accomplished in two ways. First, change the focus from making sustainable components (the individual elements of the larger system, the buildings, vehicles, roads, parks) to making sustainable systems. The latter includes the former, but not vice versa. For planning and design, this means shifting from a project focus to the performance of neighborhood systems and the larger urban-regional systems. Second, change the definition of the problem from the symptoms of environmental degradation to the root cause: current economic tools, processes, and accounting. These two changes shift the focus of our problem solving, innovation, regulation, and planning from components to the system. We must reconfigure, reinvent, and respecify the economic machinery, processes, and practices that are destroying the environmental system.

Regenerative urbanism requires expanding the focus of urban sustainability planning from a project-to-project approach to a systems approach that reconfigures our nested and interconnected districts, cities, and regions to achieve true system sustainability performance. At the center of this shift is the concept of “*biosystemsmimicry!*” The term *biosystemsmimicry* extends biomimicry's key insight of following the fundamental principles of nature's “systems” success arising over 3.8 billion years of evolution to the design and functioning of our built environment and economy. The net result would be systems-level sustainability in our urban and regional settlement systems and economy more generally. Getting there requires a strategic approach that assesses the gap between desired performance and current reality, formulates the best path to achieve the performance desired, and changes practice to produce it.

A critical premise of regenerative urbanism is the need to configure the built environment so that it integrates nature and human behavior to produce systems sustainability. Such planning and design will create circular resource flows that produce more value for both humans and nature than the current human economy. It also must address the challenges of communities with limited access to capital and disadvantaged from historical inequities that limits their resilience to climate change. The connection between climate change and its impact on disinvested communities establishes a moral and ethical challenge beyond traditional goals of planning, natural resource conservation, and eliminating greenhouse gas emissions. Thus, engagement with the stakeholders of historically marginalized communities to co-create neighborhoods that are adaptive and resilient to climate change is an important part of regenerative urbanism.

Invent New Governance Entities for Systems Sustainability Entrepreneurship

A change in the governance of the free-market economy is needed to resolve the institutional incapacities that generate the market failures leading to the dual climate and unsustainability crises and other unintended impacts. Such a market failure can only be corrected with a governance system that harnesses the free market so that it delivers its socially legitimizing effect—producing for maximum public good through private market competition, not producing maximum private good for maximum system-wide collapse.

In addition, the benefits of regenerative systems sustainability do not accrue in enough magnitude to any one market or municipal function (water, land use, transportation, etc.) to exceed the current market benefits of unsustainability. If they did, we would see a big market shift to sustainability. Furthermore, unsustainable practices are protected by many existing laws and generated by many public subsidies. Conversely, current laws make many sustainability practices illegal. In other cases, market failure renders them uncompetitive. Finally, citizens are focused on immediate needs. Thus, existing actors (government, developers, business, citizens) and the existing market will never pursue regenerative sustainability and urbanism nor generate its big value. As a result, communities interested in regenerative outcomes need a new governance entity – a sustainability champion enabled to play the long-game of ultimate regenerative sustainability systems success, and quickly in response to the closing 10–15-year window of opportunity to make sufficient progress. The new champion needs to generate and coordinate the regulations and investment that create a regenerative built environment, which in turn, creates sustainable urban economies and communities. The case summary above on Kashiwa (Japan), describes such an innovation.

Solve the Economic AND the Environmental Problem—the New Value

Cities and the built environment are a slow-to-change spatial dimension of our economy. How we plan, design, manage, and renew the built environment now fundamentally determines urban, regional, and global sustainability (or unsustainability) performance for the next 50 to 100 years or more. As a result, the added value of regenerative urbanism changes profoundly from being a nice-to-have optional aesthetic practice of urban and regional planning to being an essential economic practice. The choice is no longer the binary one between jobs or the environment, but the unitary choice of both jobs and the environment. It also reveals the falseness of the binary choice. The “jobs” of the binary choice are presented as the only job option when in fact that job option is only a short-term job option that kills the environment and then the economy. This realization reveals the real choice society faces: (1) short-term jobs that damage or destroy the economy and the environment or (2) long-term jobs that expand the life regenerating capacity of the human economy and environment. Getting from the first to the second type of jobs will require inventing effective and innovative sustainability transition policies and financing—a key aspect of the sustainability challenge.

Leverage the Built Environment–Economy Connection

Cities are the greatest technology humans have invented. In addition, they are the mediating bridge between the human economy and nature, for either positive or negative effect. How professionals plan and develop the built environment “locks in” sustainability or unsustainability performance for the long run. Thus, how we plan new city-regions and renew existing ones becomes one of the critical sustainability planning responses to the closing window of opportunity from accelerating cataclysmic climate change and unsustainability. Furthermore, recognizing the built environment as part of the economy reveals the formative role it plays in catalyzing the full sustainability response: creating the new circular ecological sustainability economy of inclusive abundance. Embracing this new value, role, and approach will usher in the new practice of urban and regional regenerative *systems* sustainability planning, design, and management.

Expand Carrying Capacity by Design—Generate Perpetual Inclusive Prosperity

The linear flows of the current economy will eventually exhaust the biosphere’s raw material inputs to the human economy. At that time, it will be too late to solve the problem. Such limits are intrinsic to our current linear approach to resource use. With it, we account only for the harvest from nature and not the harvesting’s destruction of nature’s regenerative capacity (natural capital). According to the best information available, we are reaching the limits of a linear approach in this century. The effects will exclude us all, ultimately, which is likely later this century if trends continue.

In contrast, a regenerative approach (1) mimics the self-organizing regenerative principles and processes of nature; (2) steps into the infinite loop of cycling materials in production, deconstruction, and reuse of nature’s material in subsequent rounds of production; and (3) harnesses human creativity and innovation to amplify nature’s principles and processes that expand the life support (carrying) capacity for both nature and the human economy. The ultimate result would be a human economy that produces inclusive prosperity for all in perpetuity, while also expanding the richness of nature without damaging nature. This shift creates the foundation for perpetual inclusive prosperity, with expanding productivity being the determining factor for meeting everyone’s needs. The solution is designing for infinite material cycling in the human economy without adverse effect on nature. Doing so using the principles and practices of regenerative *biosystemsmimicry*, is the only way to expand substantially the carrying capacity of the human and environmental systems to achieve inclusive prosperity. The nature economy allows for production in perpetuity through resource cycling and design for non-toxicity and deconstruction and reuse. Regenerative sustainability would use these principles as planning and design imperatives for the human economy, including the built environment.

Solve the Climate and Sustainability Crises Simultaneously

The source of the climate crisis is not GHG production per se, nor is the solution simply any method of GHG elimination by 2050 at the latest. The source is the economic machinery, processes, and accounting that produce GHGs now and for which there are no other options for the short run, nor until recently, for the long run. Another aspect is the unequal distribution of the economy from local to global scales. Those living outside the benefits of that economy are increasingly laying claim to participation. It is those claims and the absence of a win/win positive-sum framing that are undermining climate negotiations and the collective formulation and embrace of the needed massive, lightning-fast response.

To survive and thrive, humanity must shift to an ecological, regenerative, circular sustainability economy that is “hardened” against the increasingly hostile conditions of the 100+ year period of climate recalibration. Such an approach creates the basis for inclusive prosperity for a global population of 9 billion by 2050 and up to 12B by 2100. It is the primary strategy and mechanism for fully mitigating climate change and is the only approach that will likely gain the support of world leaders needed for climate success. Thus, we can and must solve the climate crisis with regenerative sustainability, thereby solving both crises simultaneously. Finally, the climate and sustainability challenges are only partly ones of innovation, invention, and diffusion of the new regenerative economic machinery, processes, and accounting. It is primarily a problem of financing the transition; that is, structuring the investment needed now to be repaid from future revenues. We have the technology and know enough about the first round of investments to begin. We simply need to formulate the work plan and financing plan for the rest of the work that will achieve success within the limited time remaining.

Use the New Urban Systems Planning & Design Practice

Since 2010, with the advent of powerful systems modeling information technology, the planning, design, and building professions are on the cusp of a new generation of a “systems” practice. Shifting to 2D-3D digital geospatial *systems* planning and design tools creates the potential for a new powerful practice: digital, object-oriented, urban and regional *systems* planning, design, and management.¹ The four pillars of this new practice are (1) 3D city base maps, (2) rule-based procedural modeling and planning, (3) interconnected WebGIS, and (4) easy automation with object-oriented programming, non-coding tools, and lite-scripting tools. These four pillars have ushered in a new world of software development. Previously, organizations would hire a group of software experts to create customized software to solve organizational problems. Now, software companies are building new platforms that streamline entire workflows, such as urban planning, with new tools: ArcGIS Urban, ArcGIS CityEngine, ArcGIS HUB, ArcGIS Indoors, ArcGIS GeoBIM, and UrbanSim. These new tools enable complex technical skills and workflows in the back end for use via simple web browsers.

This new digital system planning practice holds the potential to streamline the urban development and planning workflow and to monitor city-region systems performance, such as sustainability, for continuous improvement planning, design, and management. In addition, shifting to procedurally based geospatial *systems* planning holds the potential to scale the regenerative sustainability approach instantly for quick global diffusion. This is accomplished through the codification of regenerative principles, plans, and designs into programming rules. They are then used to generate procedural representations of form and processes that can be used to quickly test ideas and proposals in a digital twin model by iterating through many configuration scenarios in a fraction of the time it takes with current practice. In addition, those procedural rules that codify whole planning concepts (complete streets) or approaches (regenerative urbanism) can be easily and quickly shared and adapted to local conditions.

Build Inclusive Environments

During the transition to a fully regenerative sustainability economy, there is a fundamental need to connect the larger urban economy with disadvantaged communities in new ways, so they accumulate wealth. The changed economy of a regenerative built environment would meet the needs of disadvantaged communities. It would include healthy and service-rich environments focused on education and skills development. A regenerative built environment would increase nature in the neighborhood. Increased economic opportunity and nature would reduce stress, produce community cohesion, and support collective action.

Manage Resources for Regeneration

Ending linear take-make-waste resource use in designing the built environment and wider economy is the *north star* for managing resources for regeneration. There is no waste in nature. Waste in the human economy is a large unaccounted, invisible, *off-book* cost and inefficiency. Because the human economy violates regenerative principles blindly, the economy does not self-correct its fundamental market failure. Managing resources for regeneration is the correction. This correction would use resources continuously and use renewable solar and wind energy. It would end pollution and waste by reengineering processes and designing products and their life cycles for complete resource cycling and non-toxicity, and supporting those practices with laws and regulations.

Generate Community Cohesion

Cooperation and community cohesion are both a requirement of regenerative urbanism and a product of it. They are key organizing concepts in politics and urban development planning. The goal of inclusive prosperity cannot be attained with an economy that destroys nature and our planetary life support security. Thus, fixing these economic dynamics with a shift to regenerative urbanism is the first priority, and it includes equity. It will expand the carrying capacity of the economy and nature to the levels of productivity required for the inclusive prosperity of 9-12 billion people by 2050-2100 with only net positive environmental impacts. One question for the equity community that arises from a regenerative systems sustainability approach is whether advocacy work should focus on campaigns to increase participation in and share of an unraveling, increasingly toxic world, or should it focus on advancing the use of regenerative urbanism and creation of regenerative economies and communities?

Produce Systems Sustainability—Measure It for Continuous Improvement

A key characteristic of regenerative sustainability and urbanism is shifting from producing the sustainability of individual components (buildings, etc.) to producing systems sustainability. This is what can be termed “*biosystemsmimicry*” in the planning and design of the built environment’s components so that they function collectively to create a circular economy locally and beyond. The existing gap from current reality—and closing that gap—need to be illuminated with metrics and will arise from on-going innovation, practicing organizational learning, and continuous improvement of organizational and institutional norms.¹

CONCLUSION

This set of principles, imperatives, and core concepts are the key components of the emerging and powerful innovative response to accelerating unsustainability: regenerative systems sustainability and urbanism. They provide the foundation for exploring, testing, and advancing the practice for success. However, they will be applied in different ways across the spectrum of practitioners and settings, from local to international, from city to region, from economic sector to social sphere. They are the basis for the new value, new practice, and new leadership role for planners, designers, and sustainability professionals ushering in sustainability success just in time.

^a IPCC, Sixth Assessment Report.

^b Urban transition: UN DESA, Our World in Data, and Urban Population.

^c Urban Design Center Kashiwa-no-ha, the new sustainable district development entity of Kashiwa-no-ha Smart City, Japan.

^d San Francisco Planning Department, Regenerative San Francisco: Phase 1 - Explorations and Proposal for Action, April 2018.

^e ODOT, Independent Cover Assessment, I-5 Rose Quarter Improvement Project, Executive Summary, July 21, 2021

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ACCESSIBILITY EVALUATION OF URBAN PARK GREEN SPACES BASED ON MULTI-SOURCE BIG DATA AND IMPROVED TWO-STEP FLOATING CATCHMENT AREA METHOD

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ABSTRACT

With an increasing attention to the equity in public natural resource distribution, the accessibility of urban parks highlights the standard of access by proximity for building socially just ecocity. Integrating related factors, such as path, land use, income and ethnicity, recent studies have been improved with the transformation of methods from the questionnaire-based qualitative to the GIS-based quantitative. However, in the process of urban planning, the deficiency analysis of park green space distribution mostly based on the simple buffer by bird path could result in a greater assessment error. In this case study, facilitated by the multi-source big data, more specific characteristics of the spatial distribution of urban residents were identified. The improved two-step floating catchment area (2SFCA) method was employed in combined with the network analyst in ArcGIS to evaluate the actual accessibility of park green spaces in Wuxi City, China. The urban districts with low accessibility to park green spaces were mapped as the key areas for equity promotion. Compared with the traditional methods, the spatial fitting degree between service capacity of urban park green spaces and users' demand was measured more accurately. The study could conduct the layout optimization of urban park green spaces effectively.

KEYWORDS

Accessibility; Urban park green space; Multi-source big data; Two-step floating catchment area method

INTRODUCTION

Due to the global acceleration of urbanization and continuous population agglomeration, urban environmental problems (such as congestion, pollution, etc.) have received worldwide attention. As an extremely important part of urban green infrastructure, urban park green spaces (UPGSs) not only support the integrity of the urban ecosystem by contributing to pollution prevention, noise reduction, and temperature regulation, but also help to improve the quality of life of urban residents and promote urban public health [1,2]. With the enhancement of social public awareness and the increase of outdoor recreation activities, providing convenient and efficient access to the green open space has become increasingly crucial, as recognized in the international Ecocity Standards for “Access by Proximity”. However, in developing countries, due to the inadequacy and imbalance of the UPGSs, there is a universal conflict between the UPGSs supply and growing demand, not all urban residents and communities possess the same degree of access to UPGSs, which has resulted in the environmental injustice [3]. Traditional indicators of urban green space planning and construction that pursue quantities and areas, such as greenspace area per capita and green coverage rate, are hard to evaluate the spatial fitting degree between service capacity of urban park green spaces and users’ demand [4]. Therefore, evaluating the accessibility of UPGSs from the perspective of equating supply and demand is not only the further advancement of urban green space research but also the actual requirements of urban planning and decision-making, which is of great significance to improve human well-being and urban sustainable development.

At present, multifarious measurements and models have been used to evaluate the accessibility of UPGSs. Integrating related factors, such as path, land use, income and ethnicity, recent studies have been improved with the transformation of methods from the questionnaire-based qualitative to the GIS-based quantitative [5,6]. According to the reviews of Talen (2003) and Rigolon (2016) [7,8], the measurement models of spatial access to parks can be roughly divided into three categories: (1) In the supply-oriented acreage approaches, the container approach depicts the number or size of parks within a given spatial unit (for example, census tract or political district), and its evaluation result is largely built on the division size of the unit [6]. The other is the coverage approach which takes the spatial location of facilities into account and breaks through the unit limitation. The buffer analysis, network analysis, kernel density estimation, and Thiessen polygons method are used to evaluate the accessibility by setting a certain distance from urban park “sources” [9,10]. (2) In the demand-oriented spatial proximity approaches, one of the most widely used is known as the minimum distance approach, which measures access as either Euclidean distance or street network distance to the nearest facility [11]. Another one is the travel cost approach, which calculates the distance (cost) between an origin and all included parks, regardless of the park’s size and amenities. (3) The gravity potential approaches, which are based on the theory of spatial interaction and incorporates factors such as the supply side, demand side and the connecting medium into the measurement model, are more complex and advanced [12]. In particular, the two-step floating catchment area (2SFCA) method, as a dichotomous technique of the gravity-based model [13], pays more attention to the attractiveness between supply points and demand points within a specific range. The 2SFCA method can appropriately measure the potential spatial accessibility and has been widely adopted in the urban green space access studies [14].

Moreover, with the development of information technology and the rise of multi-source geospatial big data, it has become possible to in-depth characterize the spatial details and accurately quantify the spatial relationship between residents and urban green spaces [15]. The limitations and dilemmas of current green justice researches in data accuracy, measurement technology, and optimization simulation will be effectively solved. In this study, taking the central area of Wuxi city as an example, we attempted to use the big data of point of interest (POI) and residential areas crawled from the web application programming interface (API), combined with the traditional vectorized data (such as remote sensing data, statistical yearbook data and planning documents, etc.) to establish a basic database. Furthermore, based on the improved 2SFCA method, the UPGS accessibility measurement model was proposed by considering the supply of urban parks, the demand of residents, the service radius differences, the distance decay and other influencing factors. The current situation of both the supply and demand sides of urban park service was quantitatively analyzed at the plot scale, and it was confirmed that the research approach was entirely feasible. At the same time, data visualization analyses were conducted from the perspective of statistics and space to scientifically measure the spatial distribution and fairness of UPGSs. The results of the study could also provide support for the further optimization of the UPGS planning and allocation.

STUDY AREA AND DATA SOURCES

Study Area

Wuxi is a representative city in the Yangtze River Delta area in eastern China, which is situated along the Beijing-Hangzhou Grand Canal and at the waterway's junction with local rivers near northeastern Taihu Lake. This city has so long been the water transportation hub, and hence enjoyed economic prosperity and a burgeoning population. Much of the city's terrain is hilly plain with a dense water network, which endows Wuxi with a blessed natural geographical condition. By the end of 2019, the greenspace coverage in built-up areas was 43.24%, and the urban park greenspace per capita reached 14.93 m².

The high land development intensity and dense population distribution in the central urban area not only lead to huge pressure on the ecological environment but also a sharp contradiction between the supply and demand of urban park greenspace services. Therefore, the study area of this research was the central area in Wuxi, defined by the “Comprehensive Plan of Urban Land Use for Wuxi (2006-2020)”. The area covers the entirety of Liangxi District and parts of Xishan District, Huishan District, Binhu District, and Xinwu District and involves 35 subdistricts with a total area of approximately 559.19 km² (Fig. 1).

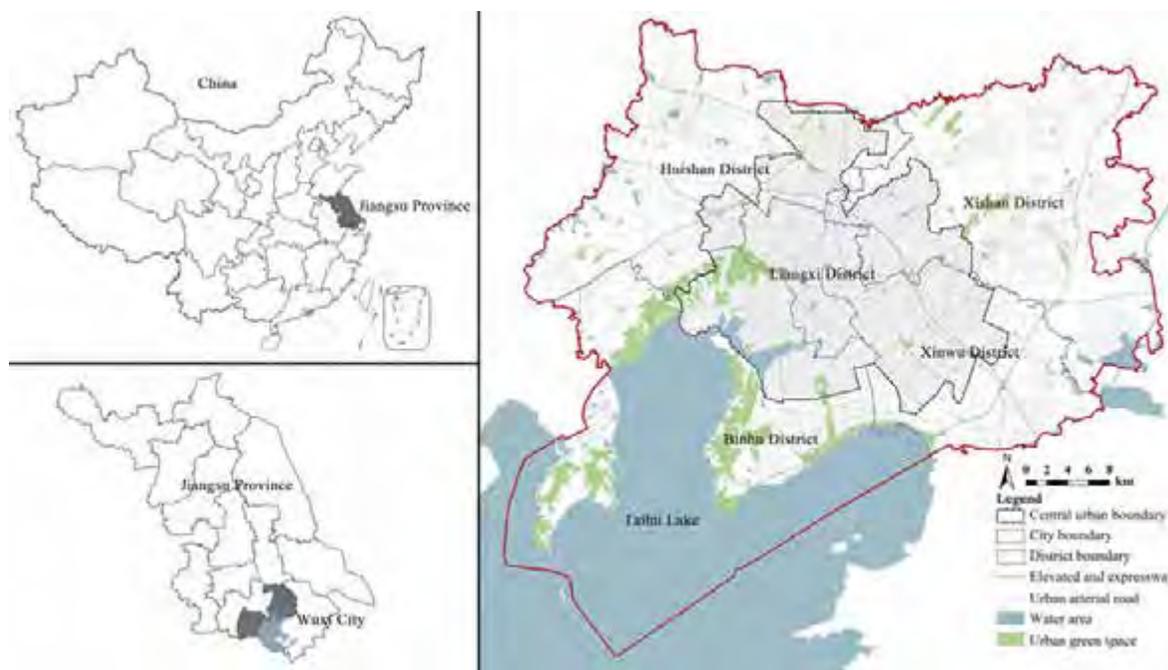


Figure 1. Overview of the study area

Data of Urban Park Green Spaces

According to the “Standard for Classification of Urban Green Space (CJJ/T 85-2017)”, the four types of urban park green spaces (G1) were chosen as the research object. These types include comprehensive parks (G11), community parks (G12), specific parks (G13) and recreational gardens (G14), as well as the land for squares (G3) with a greenness percentage greater than 65%, which could also be counted as urban park green space. Combined with remote sensing data, text and graphical documents of the “Green Space System Plan for Wuxi (2018-2035)”, the vector data of 73 UPGSs with a total area of approximately 16.78 km², excluding the vector surfaces with an area less than 0.2 hm² and width less than 12 m, were finally extracted (Fig. 2).

The point data of urban park greenspace entrances were obtained by filtering the point of interest (POI) data. Each piece of POI is a real geographic point data containing spatial information such as latitude and longitude, address, and attribute information such as name and category. In this study, the POI data from the Amap API server (<https://lbs.amap.com/api/webservice/guide/api/batchrequest>) were crawled in February 2021. Amap is one of China's web-based navigation maps, and Amap offers more accurate and specific geographical features. A total of 162 points of the entrances of UPGSs in the central area of Wuxi were filtered; and after manual correction and supplementation, we finally collected 226 actual entrance points (Fig. 2).

Data of Urban Road Network

Urban road traffic data are important basic data to explore the accessibility of UPGS. Based on the urban skeleton road network planning map in the “Comprehensive Plan for Wuxi City (2006-2020)” and the Open Street Map (OSM) data, we built an urban road network dataset in ArcGIS. The dataset shows the topological relationships, where the junctions and roads are abstracted into the nodes and links, respectively.



Figure 2. Spatial distribution of the UPGSs and entrance points

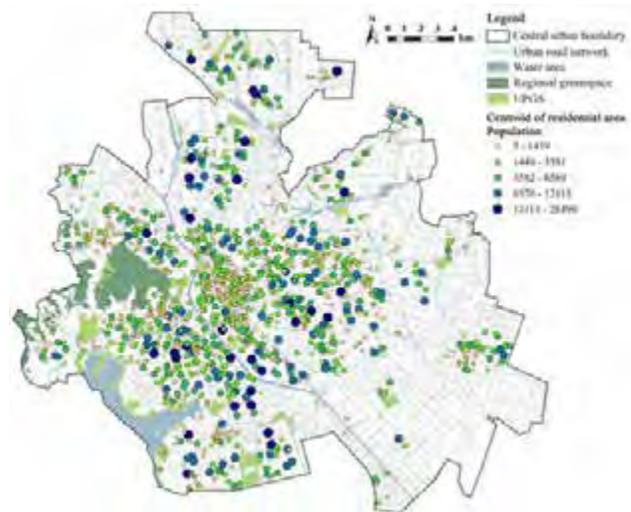


Figure 3. Spatial distribution of residential points and population

Residential Area and Population Data

The residential area data were extracted from the “Fangtianxia” website (<https://wuxi.fang.com/>) using Python code in March 2021. “Fangtianxia” is one of the largest web-based real estate transaction platforms in China that can provide masses of professional information and diverse services for housing deals, constituting a location-aware form of big data. The data contain 1400 residential areas within the central area of Wuxi; and the data include complete attributes of names, locations, the total number of households and other characteristics. In addition, according to the “Wuxi City Statistical Yearbook 2020”, the average population per household is 2.80, and the population of each residential area can be estimated (Fig. 3). Compared with the use of subdistrict centroid and subdistrict population data in previous studies, we provided necessary support for the analysis of urban park greenspace accessibility at a fine scale.

METHODS

The technology flowchart of the study is presented in Figure 4. First, a multi-source basic database was established by combining and registering the current urban land use data, the real urban road network data, and the big data obtained by web crawlers. On this basis, the supply and demand levels of UPGSs were preliminarily assessed. Second, the improved 2SFCA method was used to quantify the fitting degree between the supply and demand of UPGSs. Third, the accessibility indexes calculated by the improved model were further visualized from the perspective of quantity and space. Specifically: (1) The allocation difference of UPGSs between regions was analyzed by using the Lorenz curve and Gini coefficient. (2) Through the fitting model of trend analysis, the spatial distribution regularity of the element was simulated, and the distribution trend of the accessibility index in the study area was obtained. (3) As a discontinuous observation point, the residential area could only objectively reflect the spatial accessibility of this geographical location. In this study, the interpolation analysis was conducted to obtain the continuous spatial pattern of the accessibility, and then the spatial distribution difference and agglomeration characteristics were analyzed. Finally, the urban districts with low accessibility to UPGSs were mapped as the key areas for equity promotion at the plot scale.

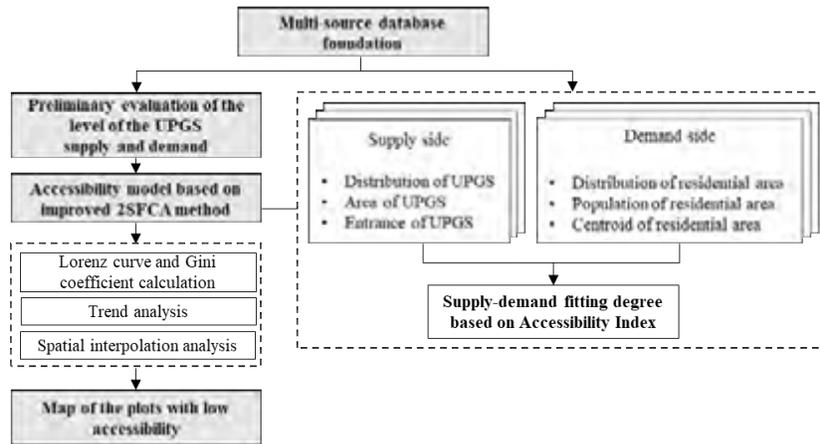


Figure 4. Overview of the study area

2SFCA Method and Its Improvement

The 2SFCA method, constructed by Radke and Mu in 2000, is a spatial accessibility measurement method based on cumulative opportunities [16]. Its main principle is to successively take the service supply point and the demand point as the search centre within the set threshold range and calculate the supply and demand situation between these two floating catchment searches. This is shown in Equations (1 and 2).

Step 1: Calculate the supply-demand ratio R_j of urban park green space j at the supply point.

$$R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \leq d_0\}}^k D_i} \quad (\text{Eq. 1})$$

where R_j represents the potential per capita enjoyment of urban park green space (m^2 per person); i is the demand point; j is the supply point; S_j is the supply capacity of j , which in this study is expressed by the area of urban park green space; D_i is the demand scale of i , which is expressed by the population of the residential area in this study; k is the number of residential areas within the catchment radius d_0 ; and d_{ij} is the distance between supply and demand.

Step 2: Calculate the urban park greenspace accessibility index A_i of residential area i at the demand point.

$$A_i = \sum_{j \in \{d_{ij} \leq d_0\}}^m R_j \quad (\text{Eq. 2})$$

where m denotes the amount of UPGSs within catchment radius d_0 of residential area i ; d_{ij} is the distance between the supply and demand; and R_j is the supply-demand ratio obtained in the first step. The main calculation process can be shown in Figure 5.

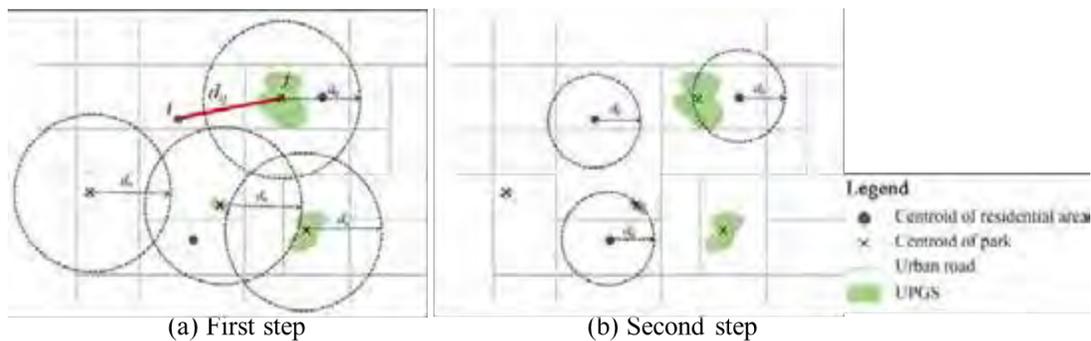


Figure 5. Representation of the traditional 2SFCA method

To address some limitations of the traditional 2SFCA method, the following improvements were adopted in this study: First, in terms of d_{ij} in the above equation, this study relied on the network analyst in ArcGIS to obtain the actual cost path between UPGSs and residential areas instead of the Euclidean distance. Second, due to the differences in the size and shape of UPGSs, the supply point, which was simply set as the geometric centre of the parks in the traditional way, could result in a greater assessment error. In this study, driven by multi-source big data, the real entrances of the urban parks were used as the first search centre. That is, the catchment area was the collection of all the entrance search scopes. In addition, for a single search radius, McGrail et al. (2014) and Zhuolin Tao et al. (2016) divided the dynamic radius and the multilevel radius with respect to demand and supply, respectively, thus improving the accuracy of the calculation results [17,18].

Therefore, according to England’s “Accessible Natural Greenspace Standards” and China’s “Standard for Planning of Urban Green Space (GB/T 51346-2019)”, we divided the extracted UPGSs into city level, district level, subdistrict level and street level based on the different scales. Correspondingly, the service radii were set as 5000 m, 2000 m, 1000 m and 500 m. Based on these multilevel service radius thresholds, the ranges of the reach of the demand side to different levels of UPGSs were determined, which also served as the basis for calculating the coefficient of distance decay, as shown in Table I.

Table I: Multilevel Service Radius and Range of The Multilevel reach

| | Service radius/m | Urban park greenspace level, Area/hm ² |
|--------------------|-----------------------|---|
| Supply side | 5000 | City level, ≥ 50 |
| | 2000 | District level, [10, 50) |
| | 1000 | Subdistrict level, [5, 10) |
| | 500 | Street level, [0.2, 5) |
| | Range of the reach /m | Up to the level of urban park greenspace |
| Demand side | (0, 500] | City park, district park, community park, street park |
| | (500, 1000] | City park, district park, community park |
| | (1000, 2000] | City park, district park |
| | (2000, 5000] | City park |

Third, in the traditional method, the demand point is deemed to be able to enjoy the service facility within the given catchment area, ignoring the basic rule that as the distance increases, the attractiveness of the supply point to the demander decreases. To address this problem, Dai (2011), Wang (2012) and other scholars proposed and introduced a power function, a kernel density function, a Gaussian function, and other distance decay functions [19,20]. The Gaussian function was selected and combined with Equation (2) because its decay rate is first fast and then slow as the distance increases, which is broadly in line with the actual situation of the research object in this study. This is shown in Equations (3 and 4).

$$A_i = \sum_{i \in \{d_{ij} \leq d_0\}} R_j G(d_{ij}, d_0) \tag{Eq. 3}$$

$$G(d_{ij}, d_0) = \begin{cases} \frac{e^{-\frac{1}{2} \times \left(\frac{d_{ij}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}}, & d_{ij} \leq d_0 \\ 0, & d_{ij} > d_0 \end{cases} \tag{Eq. 4}$$

In the formula, G is the Gaussian function, d_{ij} is the distance between the two points of supply and demand, and d_0 is the service radius. The improved calculation process is shown in Figure 6.

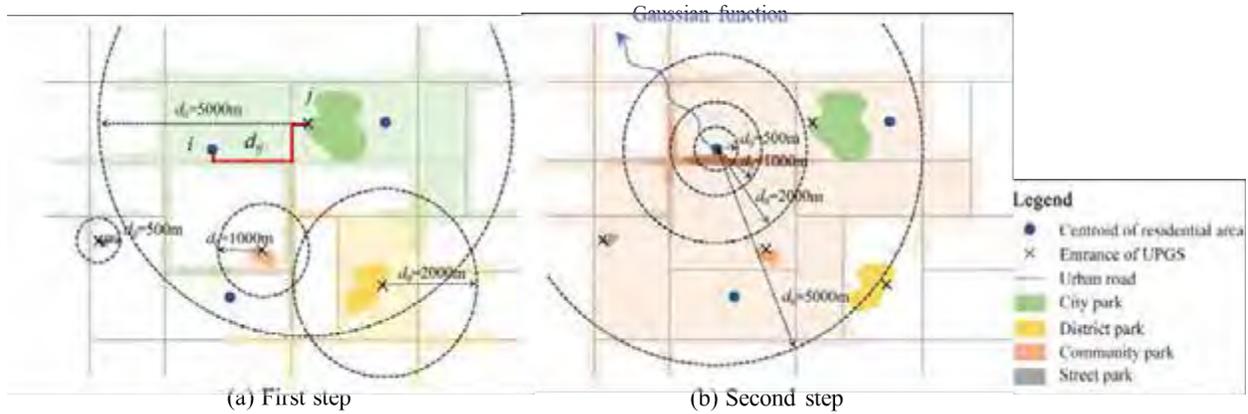


Figure 6. Representation of the traditional 2SFCA method

ANALYSIS AND RESULTS

Preliminary Assessment

As shown in Figure 7, a preliminary assessment of the supply and demand levels of the current urban park greenspace distribution was formed. The current UPGSs were concentrated in the “Xibei Canal” area (A) in Huishan District, the “Xihui-Grand Canal” area (B) in Liangxi District, the “Lihu-Liangxi River” area in Binhu District (C), and the “Bodu River” area in Xinwu District (D), presenting a multicore distribution. The larger parks were mainly distributed around the periphery of the central area due to relying on urban natural resources, and there were a few community parks and recreational gardens in the central area.

In this study, three types of land use in cities, towns and villages were thought to be closely related to the distribution of population. We built the spatial connections between these land use data and the population data of the residential communities covered; thus, the distribution difference at the population scale among the plots was preliminarily distinguished. The areas with a higher population density were particularly distributed along the “Grand Canal”, “Liangxi River” and “Xicheng Canal”; and the results reflected the spatial heterogeneity of residents’ demand for UPGS to some extent.

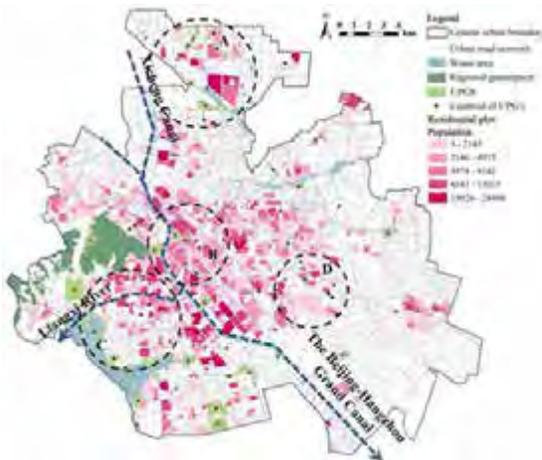


Figure 7. The preliminary assessment of supply and demand

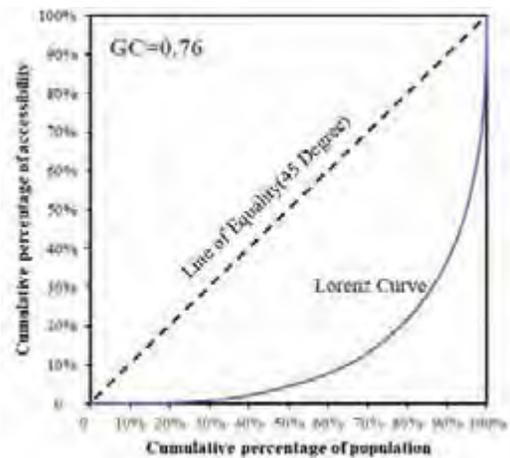


Figure 8. The Lorenz curve and Gini coefficient

Accessibility Evaluation of the UPGS distribution

In order to quantitatively reflect the fitting degree between supply and demand, the supply and demand points were used as centres to perform floating catchment searches respectively. Finally, the accessibility index of UPGs for each residential area was calculated by using the improved 2SFCA method.

First, the Lorenz curve and Gini coefficient were used to explore the difference of resource distribution and accessibility of UPGs in the central area of Wuxi. The Lorenz curve and Gini coefficient are always used as quantitative indicators of social equity performance evaluation. They were first proposed by Lorenz, an American statistician, to explore the issue of income distribution equality, mainly using mathematical methods to quantify the gap between the rich and the poor [21]. The income distribution based on the connotation of social equity is similar to the distribution of public resources in essence. Therefore, in recent years, this method has been widely used in various fields to study the related issues of inequity in resource allocation. In this study, the Python code was used to calculate the Gini coefficient (GC, range:0-1) by arranging the measurement results in ascending order to obtain the functional relationship between the cumulative population percentage and the cumulative accessibility percentage. As shown in Figure 8, the more curved the curve was, the more inequity in the spatial distribution of UPGs was. The GC was finally calculated at 0.76, which had exceeded the “warning line” of 0.4 [22]. Thus, the spatial distribution of UPGs in the central area of Wuxi was extremely unequal.

Second, the spatial distribution regularity of this geographic element was further explored through the trend analysis. In this study, As shown in Figure 9, the locations of the demand points were plotted on the XY-plane according to latitude and longitude. Above each de-mand point, the value of the accessibility index was given by the height of the Z-dimension. The values were then projected onto the XZ-plane and YZ-plane as scatterplots, and polynomials were fit through the scatterplots on the projected planes. In this study, a second-order polynomial was used to show the trends in the data, and the trends were accentuated. The curves on the projected planes suggested that there was an obvious spatial gradient pattern of the accessibility index. That is, the accessibility index gradually increased from the centre of the study area towards all the borders, and the trend of the data fitting was more obvious in the Y-dimension (north-south direction), indicating that the gradient was relatively apparent.

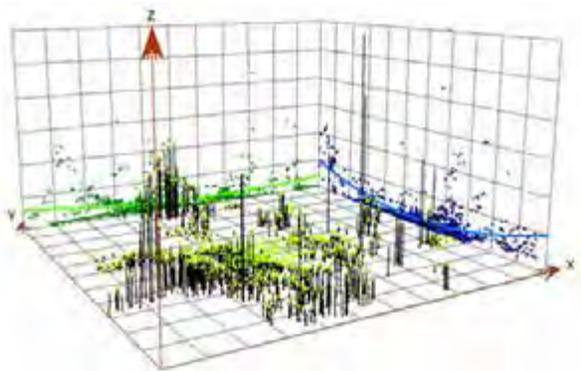


Figure 9. Trend analysis of the accessibility index



Figure 10. Spatial interpolation analysis of the accessibility index

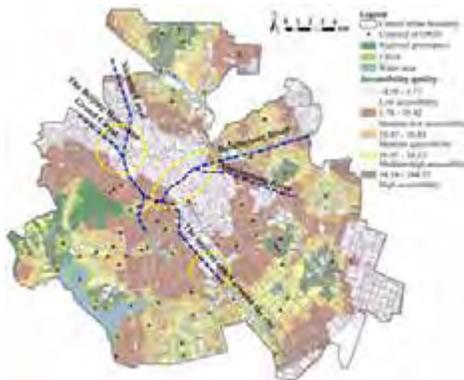


Figure 11. The accessibility quality classification of the plots



Figure 12. The results of the buffer analysis

Third, the spatial continuity trend of the fitting degree of supply and demand can be described by interpolation analysis. In this study, the empirical Bayesian kriging method without transformation was used. As shown in Figure 10, the agglomeration areas with a high accessibility index were distributed in a “U” shape at the periphery of the central area, mainly because there were several large UPGSSs in this area with many entrances but the surrounding population was relatively low. In contrast, the agglomeration areas with a low accessibility index represented by the Guangruilu subdistrict, Guangyi subdistrict, Shangmadun subdistrict and Jianghai subdistrict mainly extend from the centre to the northwest in the study area. Meanwhile, the interpolated raster data above were converted into point data, and each current land use plot was given the average value of all the points within its boundary. Then, the accessibility quality was classified into five levels (low, medium-low, medium, medium-high, and high) by using the natural breaks (Jenks) method. In this process, the accessibility evaluation is directly linked to the planning layout, and the plots with low accessibility to UPGSSs were mapped as the key areas for equity promotion (Fig. 11).

DISCUSSION

According to the multilevel service radius set in Table I, the buffer analysis method commonly used in traditional planning was adopted for multi-ring buffer analysis (Fig. 12). The results showed that most areas of the central area in Wuxi were within the service scope of the existing UPGSSs, and most of the urban residents and communities could possess better access to the urban parks. However, through the analysis results of the improved 2SFCA method adopted in this study, we found that the current distribution of the UPGSSs in the central area was imbalanced, with poor fairness, and the existing UPGSSs could not achieve universal enjoyment. Because the buffer analysis method only takes the UPGS as the research subject, without considering the users of the urban parks, the analysis results are relatively too simple and extensive. Currently, the new concepts of a “park city” and a “community life circle” proposed in China are signs that the human scale has been brought into focus in the construction of the urban living environment [23]. In the central area of Wuxi, there have also been several recreational gardens built by residents or social groups, which fully demonstrates the all-people awakening of “green” awareness. Therefore, the traditional accessibility measurement methods such as the simple buffer by bird path are difficult to meet the requirements of current human-scale planning and design. In this study, facilitated by the multi-source big data, the improved 2SFCA method that could fully reflect the population distribution and the demand differentiation was adopted at the plot scale to finely evaluate the fitting degree between the supply and demand of UPGSSs, which may be a meaningful supplement to the planning method of the current urban green space system.

Given the improvement of accessibility, the optimization suggestions from three aspects are put forward in this research: supply side, connection medium and demand side. (1) In terms of UPGSSs, it is necessary to balance the spatial layout of UPGSSs. On the one hand, the existing UPGSSs should be reconstructed or upgraded to improve the quality of the environment, like promoting the service facilities or enriching the recreational activities. On the other hand, the newly added UPGSSs should be fully integrated into the construction of the park system in the whole region. In this process, priority is given to the areas with low accessibility. Based on China’s special land policies and various plans, the new UPGSSs are added to eligible areas to ensure the maximum service coverage and service overlap rate of the large-scale UPGSSs, while in the compact old town, it is more efficient to increase the number of the small-scale UPGSSs. In view of the Wuxi city with a special landscape pattern, the newly added UPGSSs for improving accessibility should be fully integrated with the urban water network structure. Particular emphases were placed on the key nodes of the river’s confluence and the construction of green belts along the rivers, furthermore, the belt parks also possess higher accessibility. Examples include the Y-shaped confluence area of the Beijing-Hangzhou Grand Canal and Xicheng Canal and the adjacent areas along the Beixingtang River, the Xinxingtang River, and the Ancient Canal around the city (Fig. 11). (2) In this study, the urban road network is used as a connecting medium, and its accessibility directly affects whether residents can easily and quickly reach the urban parks. First, the blank road network should be improved to strengthen road connectivity between UPGSSs and residential areas. Second, the number of dead-end roads should be reduced, rely on the construction of the existing expressway around the city, putting the low-level road into the municipal management. Third, the road level should be improved so that more entrances can be formed. Finally, the construction of bus routes or greenways should be optimized to connect the urban parks and other major public facilities to provide more opportunities for residents to visit the UPGSSs through green commuting modes. (3) For the demand side, the big data of residential areas crawled in this study includes not only the “total number of households” used in this research but also the “average house price”, “community greening rate”, “property costs” and other attributes, which can reflect the social and economic status of residents to a certain extent, laying a foundation for further analysis of demand differentiation under the division of social groups. To obtain more accurate results, some subjective preferences that affect the residents’ choice can be further incorporated into the evaluation model, such as the distance and time cost to the urban parks, the safety and security, as well as the public service facilities around the green spaces.

CONCLUSIONS

In the case study of the central area in Wuxi, the equity of UPGS distribution was quantitatively measured by the accessibility evaluation. The improved 2SFCA method was employed in combination with the network analyst in ArcGIS, the real entrances of UPGS as search centres, multiple radii, and the distance decay function, which satisfied the visualized expression of spatial heterogeneity of the fitting degree between the service capacity of UPGSs and users' demand. Facilitated by the combined application of multi-source big data and traditional data at the fine scale, the accuracy of calculation was improved and the results could be fully integrated with the planning practice. For further optimization of UPGS layout and site selection, the targeted suggestions were also put forward. In future work, more non-spatial factors, such as per capita income and age of residents, should be included to promote the research methodology.

FUNDING

This work was supported by the [National Key Research and Development Program of China #1] under Grant [number 2019YFD1100405]; and [National Natural Science Foundation of China #2] under Grant [number 51838003].

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ASSESSMENT OF EXPOSURE AND ADAPTATION OF COASTAL MILLION-CITIES IN AFRICA TO SEA LEVEL RISE IMPACTS

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ABSTRACT

Many environmental and socio-economic issues impacted in many African settlements, especially the big cities. The study aims to identify the highly exposed cities to impacts of sea level rise (SLR) to recommend suitable adaptation strategies. The exposure analysis is based on some city's characteristics; population, area, density, elevation, and importance. Due to high changes in global climate and social circumstances, there are twenty-four vital million-cities in the African coastal zone (from the shoreline to +20 above sea) that exposed to SLR threats (i.e. coastal flooding, erosion, storms, saltwater intrusion). The strategic spatial planning for these cities should be based on a group of SR adaptation strategies that are appropriate to the circumstances of every city. The exposure analysis is an essential base to set an integrated framework to support their resilience against SLR impacts. Furthermore, proactive adaptation is more economical and more effective than reactive adaptation. Accommodation strategy is very urgent to redesign the building and the infrastructure to adapt to the raised SLR rate by the precise supervision of local authorities. A protection strategy is required for high-density areas, the hard works could be used in front of severe waves, while softworks could be used in high tides or weak waves that create wide and eco-beaches. Avoid strategy or do nothing is an appropriate strategy for the highly exposed open spaces. Retreat strategy could be used when the cost of protection is higher than the value of the assets. All of adaptation works in these strategies are shared between civil and governmental parts. Also, the developers and designers should be well trained and aware of all changes. Moreover, it should do a frequent reassessment of SLR hazards every seven years to be updated with changes.

KEYWORDS

Sea level rise, Africa, coastal million-cities, exposure, adaptation

INTRODUCTION

The negative reactions that resulted from activities of human and nature cross ages have resulted in a phenomenon of global climate change. It became a physical issue at the global and regional levels (IPCC, 2014). While Africa contributes slightly to the increased rate of global greenhouse gases emissions (GHGs), it is considered the most exposed to the impacts of climate change (UNEP, 2001). Sea level rise (SLR) is considered from the most serious impacts on Africa that sourced from the existence of climate change. SLR impacts have become a true fact that increasingly challenge coastal zones all over the world (El-Shahat et al., 2020). There are many SLR scenarios based on the current rise, for example, the IPCC SLR scenarios. SLR is resulting in high waves, high tidal range, saltwater intrusion, storm surges, other extreme events. These hazards could generate a likely potential risk from the processes of inundation and erosion, which could be resulted in lost in lives and assets, as already happened in most African cities. The rise in sea level is accelerated that will change the shoreline around many coastal zones in every coastal country. Therefore, SLR impacts on the environment, urban, and activities are likely increasing negatively upon times especially in the coming decades.

The exposure rate of elements to SLR hazards varies according to many factors; such as topography, slopes, proximity to the coast, soil type, population numbers, and land cover. Population growth and rapid urbanization are among the driving factors behind the increased exposure of African settlements to natural hazards, Africa's urbanization rate is the highest in the world, which reached 3.3 percent annually between 2000 and 2005 (The world bank, 2010). African topography varies due to high dynamic changes in tectonic and climatic events. Most parts of the African coastal zone are classified as low-lying areas. The coastal cities in Africa are exposed to SLR impacts, especially those that are adjacent to the shoreline and/or existed in the low-elevated areas. The livelihood in African settlements is mainly connected to the site's resources, which means that any impact from SLR hazards can weaken the settlement's strength against the potential risks. Also, the poverty rate in the African coastal zone is growing up, especially due to unsustainable development and conflicts. As well as, the African shorelines are degraded due to damming rivers, pollution, fuel overexploitation processes, mining processes, and coastal engineering works.

Most coastal cities in Africa have habitats for ecosystems (i.e. forests, wetlands, mangroves, estuaries) that have large communities of flora and fauna. Also, they have many other natural resources and human capabilities. Despite this variety of resources, they are suffering from a cruel nature. As African cities suffer from low capacity to adapt to extreme weather events (El-Raey et al., 1999), the stressors could be more devastating on the urban system with time. Recently, African cities have suffered from slums growth, poverty, weak urban management, and low technology (UN, 2014). One-third of Africa's urban population is already concentrated in the region's 36 cities with more than one million inhabitants (million-cities), most of the remaining two-thirds are spread across 232 intermediate cities and periurban areas (The world bank, 2010). Also, climate change and political issues had resulted in a decrease in the number of work chances, which forced people to migrate to big cities (Werz & Conley, 2012). Therefore, the exposure's consequences in these cities have been increased. The projected rise in sea level will have significant impacts on the coastal megacities of West Africa, where 40% of the population live, because of the concentration of poor populations in potentially hazardous areas that may be especially vulnerable to such changes, other coastal and deltaic areas at risk are those located in North Africa and southern Africa (Ndaruzaniye, et al., 2010).

THE METHODOLOGY AND STUDY AREA

The study aims to assess the exposure and adaptation of coastal million-cities in Africa to SLR impacts. The study based on the indicative analysis in the first stage (exposure assessment) and deductive analysis in the second stage (adaptation assessment). The exposure assessment for selected cities is based on five parameters; population, area, density, elevation, and importance. It has been used GIS application (ArcMap 10.3) as a study tool.

Africa had passed with devastating events resulting from climate change, which changed the urban pattern to be as shown in Fig. 1. The coastal zone in Africa has become a dense pattern of big cities compared to the inland cities, where are high population densities with a concentration of heavy activities. The continent's coastline is shared between thirty-three coastal countries with more than 26,000 km long. The area that existed between the shoreline and contour line +20 above the sea is a vital and critical zone due to specific reasons as mentioned in table 1, including a dense urban network as shown in Fig. 2. This zone in Africa varies in width from a few 100 meters (e.g. Red Sea area) to more than 100 km (e.g. Niger and Nile deltas). The area that existed in this zone has vital elements; such as valuable lands, ecosystems, and assets. Some of these elements are highly sensitive (i.e. natural protected areas, heritage buildings). This zone supports significant economic activities in the coastal countries (i.e. agriculture, tourism, commerce, and industry) through coastal ecosystem services. Also, it has vital cities that considered a developmental and social core for humans and habitat for ecosystems. For instance, some of those cities are the capital of the coastal counties as shown in Fig. 3. Many other coastal cities are also important ports, which are vital sites for national and regional trade. Although their location has generated a strong economic base, they have been exposed to many hazards, especially in light of their high population growth rate. This zone also is directly exposed to SLR impacts, particularly that adjacent to the shoreline. Therefore, there is an urgent demand to protect these cities from potential risks.

Table 1. Reasons for study's concern with the area between the shoreline and +20 m above sea level

| Area | (0-5 m) | (5-10 m) | (10-15 m) | (15-20 m) | (< 20 m) |
|-----------------|---|---|--|--|--|
| Characteristics | These areas are highly adjacent to the coast. | Many parts in this area have dunes and cliffs (coastal belts) that are prone to erosion and penetration from waves & tides. | This area is the most impacted by storm surges (exceeding 7 m), saltwater intrusion, and other extreme events. | 15-20: high plateaus associated with continental shelf are prone to SLR. | > 20: this area is safer from SLR hazards. |

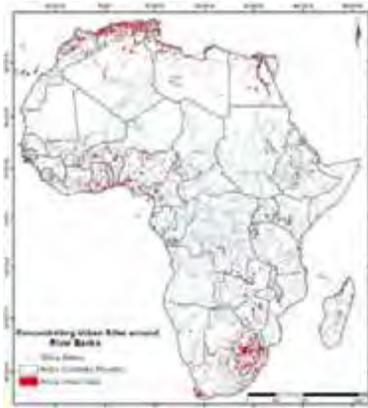


Fig. 1. The recent concentrating of urban network.

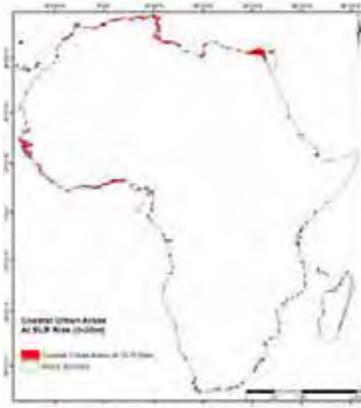


Fig. 2. Coastal urban areas at SLR risk



Fig. 3. Most of the capital cities are adjacent to the coast

EXPOSURE CLASSES OF COASTAL MILLION-CITIES IN AFRICA TO SLR IMPACTS

Million-cities in Africa that located in the area < +20 m above the sea are highly exposed to SLR impacts, especially the adjacent margin to the sea or the ocean. The million and the most important cities that existed in < +20 m are shown in Fig. 4. Those million-cities are located in the approaching areas on the marine and riverine areas, due to variations in natural resources. The table 2 is displaying the main exposure factors of these cities; elevation, population, area, density, and importance. Accordingly, it can be classified the exposure classes of these cities to be as shown in table 3.

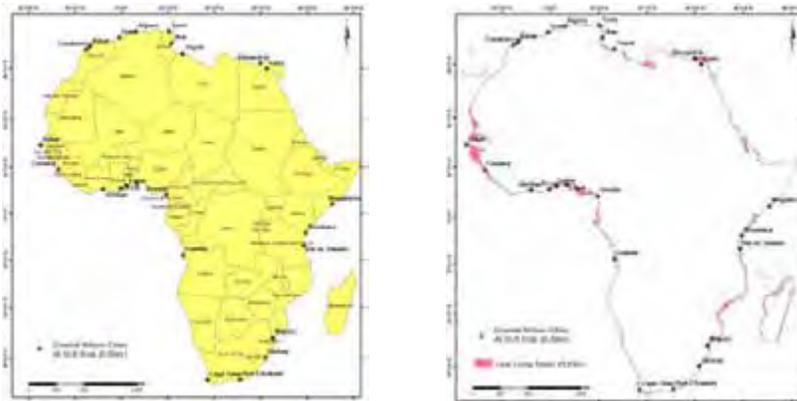


Fig. 4. Highly exposed million and most important cities in Africa to SLR impacts

Table 2. The most exposed cities to SLR impacts

| City | Elevation | Population | Area | Density | Importance |
|----------------|------------|------------------|--------------------------|--------------------------|--|
| Cairo | (15-30 m) | 9,500,000 (2015) | 3,085 km ² | 17,992 /km ² | Capital and the largest city of Egypt |
| Alexandria | (0-25 m) | 5,172,387 (2017) | 2,679 km ² | 1,900/km ² | Second important and second largest city in Egypt |
| Tripoli | (10-80 m) | 1.126,000 (2014) | 400 km ² | 4,500/km ² | Capital and the largest city of Libya |
| Tunis | (2-40 m) | 1,056,274 (2014) | 212.63 km ² | 9,406.01/km ² | Capital and the largest city of Tunisia |
| Sfax | (0-15 m) | 280,566 (2014) | 56 km ² | 5, 010.1/km ² | Essential economic city in Tunisia |
| Algiers | (5-420 m) | 3,415,811 (2014) | 363 km ² | 9,400/km ² | Capital and the largest city of Algeria |
| Oran | (0-120 m) | 852,576 (2010) | 2,121 km ² | 9,530 /km ² | The second important in Algeria |
| Rabat | (0-160 m) | 827,577 (2014) | 118 km ² | 4,896 km ² | Capital city of Morocco and its second-largest city |
| Casablanca | (0 -150 m) | 3,359,818 (2014) | 306 km ² | 10,979.3/km ² | The largest city in Morocco. |
| Dakar | (8-30 m) | 1,030,594 (2015) | 83 km ² | 12,416.8/km ² | Capital and the largest city of Senegal. |
| Conakry | (4-110 m) | 1,660,973 (2014) | 450 km ² | 3,700/km ² | the capital and the largest city of Guinea. |
| Abidjan | (3-100 m) | 4,980,000 (2016) | 2,119 km ² | 2,350.2/km ² | The economic capital of Côte d'Ivoire (20% of the population), a fourth populous city in Africa. |
| Accra | (5-100 m) | 2,291,352 (2012) | 200 km ² | 11,456.8/km ² | Capital of the Republic of Ghana. |
| Lomé | (3-40 m) | 837,437 (2010) | 99.14 km ² | 9,305/km ² | Capital and largest city of Togo. |
| Lagos | (2-50 m) | 8789133 (2005) | 1,171.28 km ² | 11,168/km ² | The most populous and financial city in Nigeria, second most populous in Africa. |
| Douala | (2-20 m) | 2,446,945 (2012) | 210 km ² | 11652/km ² | the largest city in Cameroon and its economic capital |
| Luanda | (4-80 m) | 2,487,484 (2018) | 113 km ² | 22,000/km ² | Capital and largest city in Angola, |
| Cape Town | (0-170 m) | 3,740,026 (2011) | 2,499 km ² | 1,496.6/km ² | Coastal city in South Africa. |
| Port Elizabeth | (2-70 m) | 876,436 (2011) | 340.78 km ² | 2,571.9/km ² | One of the largest cities in South Africa; |
| Durban | (2-80 m) | 595,061 (2011) | 225.91 km ² | 2,600/km ² | The third most populous in South Africa |
| Maputo | (5-70 m) | 1,094,628 (2007) | 346.77 km ² | 3,200/km ² | Capital and the most populous city in Mozambique. |
| Dar es Salaam | (2-50 m) | 4,364,541 (2012) | 1,393 km ² | 3,100/km ² | Capital, the most populous and economic city in Tanzania |
| Mombasa | (4-50 m) | 1,200,000 (2016) | 229.7 km ² | 5,224.2/km ² | The oldest and second largest city in Kenya |
| Mogadishu | (4-70 m) | 2,425,000 (2017) | 103 km ² | 23,543.7/km ² | Capital and most populous city of Somalia. |

Note: Most of these mentioned elevations in the table are an average of elevations in the city, some of the coastal margins of these cities are low-lying areas that are highly exposed to SLR impacts.

Table 3. The exposure's classes of these cities to SLR impacts

| City | Exposure Level | City | Exposure Level |
|------------|------------------|----------------|----------------|
| Alexandria | Highly exposed | Algiers | Low exposed |
| Tunis | | Oran | |
| Sfax | | Rabat | |
| Cairo | Moderate exposed | Casablanca | |
| Tripoli | | Conakry | |
| Dakar | | Abidjan | |
| Lomé | | Accra | |
| Lagos | | Cape Town | |
| Douala | | Port Elizabeth | |
| Luanda | | Durban | |
| Mombasa | | Maputo | |
| Mogadishu | | Dar es Salaam | |

POTENTIAL SLR ADAPTATION CHANCES FOR MILLION-CITIES IN AFRICA

The natural disasters induced coastal floods, storm surges, tsunamis, droughts, forest fires, and diseases are weakening the capacity of the African coastal zone, which grew the exposure of the coastal communities to SLR threats. Moreover, low capacity in African cities is increasing due to many negative factors; such as high rate of poverty, wars, low technology, poor infrastructure, unsustainable management, weak institutions, and shortage in services. The highly exposed shorelines of these cities are the low-lying margins, which deteriorated by the negative human activities. The natural sand belt and mangrove forests that protect most of the African cities against SLR impact are deteriorated due to the growth of urbanism and activities. Most of the African coastal countries are facing SLR by separate action plans at the local level associated with hard coastal engineering works, while the developed coastal countries are developing their responses against SLR impacts to sustain their coasts, especially that in the low-lying areas, via SLR adaptation policies and strategies based on many studies and field experts. Adaptation to the SLR threat is an urgent need in light of future scenarios, which may become true and worsen the situation if there is no pre-actual adaptation.

Coastal million-cities are needing to adapt to SLR and other hazards, to be more resilient in the face of different risks. Although there are significant reductions in global and national GHGs emissions recently, SLR responses may reduce these impacts rate during the coming centuries. The potential responses against SLR hazards to sustain the coastal million-cities are mitigation and adaptation, which poured in specific SLR policies and strategies. As well, other programs could be merged with them; such as programs of resilient-cities, eco-cities, green-cities, smart-cities, sustainable-cities, heat islands, disaster risk reduction, and... Mitigation policies are a precise agenda that orientates the governmental and civil institutions to decrease the GHGs emissions rate in the atmosphere by certain legislation and codes. Adaptation is related more to actions, which is a local activity based on many procedures to protect nature or population or both from SLR.

Adaptation is a holistic process based on data (actual) and predicted variables to adjust and face the SLR changes. Because of uncertainties and complexities in this science, it depends on accurate prediction in meteorological, political, or economic aspects (i.e. scenario, models). Scenarios are identifying the hotspot areas by overlapping layers. Reducing the impacts of SLR is through many changes at the private and public levels, such as coastal defenses. The costs of anticipatory adaptation for exposed coasts are much less than the cost of autonomous adaptation during times of catastrophes. The most common strategies of adaptation are protection, accommodation, retreat, and avoid (IPCC, 2007) & (DEFRA, 2006).

Protection strategy is used to manage the shoreline by soft (e.g. nourished beaches, dunes, bio-engineering, wetland restoration) and hard (e.g. revetments, bulkheads, detached breakwaters, seawalls,) coastal engineering works. Soft works are more eco, cheap, and sustained to the environment, but they need continuous maintenance. Although the hard solutions are expensive, they are used widely between the African coastal cities due to long-term life. While soft solutions can provide a habitat for ecosystems, hard solutions can cause erosion in the adjacent unprotected shoreline.

Accommodation strategy is used to manage human activities (i.e. structures, infrastructure) through flood-resilience measures, such as emergency evacuation planning, warning systems, modification of land use, redesigning of structures, upgrade infrastructure, management practices, building codes, hazard insurance and protect risked ecosystems. For instance, raising the floor levels of properties, converting land from residential areas to open spaces, low capital investments in the risked lands, renewing of wetlands, dune rehabilitation, etc.

Retreat strategy is used to setback human activities away from the high potential existence of inundation or erosion hazards through managed and restricted plans. Also, the retreat strategy is based on cost and profit analysis, for example, if the land value is less than the protection works, the gradual retreat will be applied by the local authorities. Avoid strategy is used to do nothing in the high potential SLR risk that could be used as recreation areas or bio-swallow for surface floods.

Moreover, these SLR adaptation strategies should be used with suitable policies and developmental approaches, as shown in table 4, to protect the exposed shores from SLR hazards in light of the classification of a precise exposure assessment of coastal zones in every city. But to identify the exposure levels of urban areas, it should identify the appropriate SLR scenario and the used modeling, which should be based on a precise and actual database. Therefore, the SLR adaptation policies and strategies associated with appropriate developmental approaches should be included in an integrated framework to produce more resilient cities as shown in Fig. 5. The implementation process of this framework should be a shared process between social and governmental parts that are well-trained. Also, the framework should be updated every seven years through a reassessment process.

Table 4. The developmental approaches and related SLR adaptation policies

| Approach | Principle | Objectives | Policies |
|-----------------------------|----------------------------------|---|---|
| Caution/limited Development | Lose (human uses) - win (nature) | <ul style="list-style-type: none"> Preserving nature and neglecting human needs. Employ softer, greener shoreline treatments where appropriate. | <ul style="list-style-type: none"> Avoid new development in potential risk areas. Retreat/ setback any activity that increases the exposure. Dominant uses are agriculture, wetland, and open space. Heavy structures are restricted. Property acquisition and conservation programs are focused on this area. Shoreline protection with soft armoring. Risked buildings are gradually moved out and replaced with natural protection and open space. This can be applied by downzoning to low density. Encouraging the light industries (handcraft works, fisher industries, ...). |
| Balanced Development | Win (nature) - win (human uses) | Sustaining the nature and filling the needs of human | <ul style="list-style-type: none"> Increasing resilience of highly exposed areas (technological, institutional, human capital, risk reduction, information management). Improving flexibility of highly exposed natural systems (mitigation, rehabilitation, ...). Increased social awareness and preparedness. Zones accommodation of structure (codes for elevation, footprint) Limited urbanization is surrounded by open areas. |
| Intense Development | Lose (nature) - win (human uses) | Filling the needs of humans and depleting the natural resources. | <ul style="list-style-type: none"> Increasing infrastructure and long-term investments. Dense urbanization (residential, industrial, commercial, and tourism building) and infrastructure. Intensive shoreline protection. |

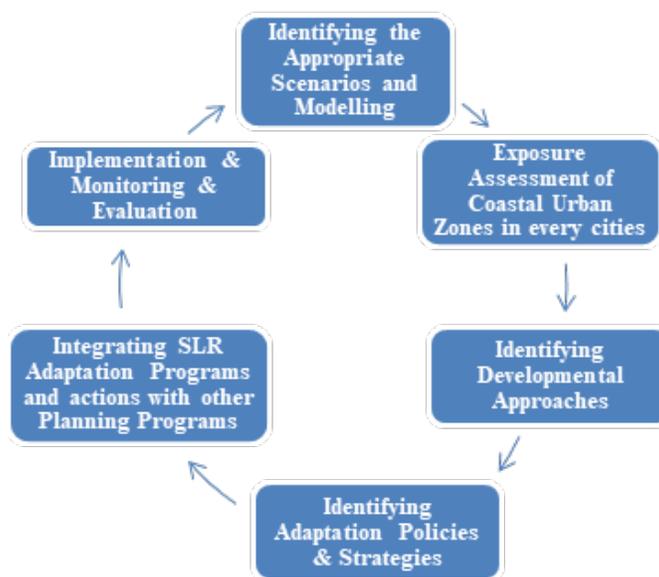


Fig. 5. An integrated framework to be more resilient cities

CONCLUSION

Because of climate change impacts that faced the African lands, the urban pattern has concentrated towards the coasts. The area that existed between the shoreline and contour line +20 above the sea is a vital and critical zone, which has a dense urban network. African big cities that have about a third of the population are suffering from many social diseases, such as poverty, conflicts, and slums. Besides that, they face many serious environmental threats, SLR is one of the most destructive hazards, especially that close to the shoreline with high density (twenty-four cities). While the coastal million-cities are representing a vital social and economic role in their countries, they are highly exposed to SLR impacts, especially the adjacent margin to the sea or the ocean.

The strategic spatial planning of these cities should have a group of selected SR adaptation strategies that are appropriate to the circumstances of every city. The exposure analysis is an essential base to set an integrated framework to support their resilience against SLR impacts. Furthermore, proactive adaptation is more economical and more effective than reactive adaptation. Accommodation strategy is very urgent to redesign the building and the infrastructure to adapt to the raised SLR rate by the precise supervision of local authorities. A protection strategy is required for high-density areas, the hard works could be used in front of severe waves, while softworks could be used in high tides or weak waves that create wide and eco-beaches. Avoid strategy or do nothing is an appropriate strategy for the highly exposed open spaces. Retreat strategy could be used when the cost of protection is higher than the value of the assets. All of the adaptation works are shared between the social and governmental parts. The developers and designers are well trained and aware of all changes. Moreover, it should be a frequent reassessment of SLR hazards every seven years to be updated with changes.

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INTERNATIONAL LAW'S INFLUENCES IN INDONESIA'S MARINE PLASTIC POLLUTION REGULATION

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ABSTRACT

This research describes the influences of international law to domestic regulation in Indonesia's marine plastic pollution. Although protection of the marine environment comes in various forms, all such methods employed ultimately rely on legal instruments as a backbone. However, the question of whether such legal instruments are sufficient to prevent marine pollution in the domestic level remains unanswered. This research seeks to answer: To what extent do the international legal instruments on marine protection influence domestic regulations on marine plastic pollution? This research provides brief outlines of current international laws and Indonesian regulations, followed by a closer look on the regulations of two cities: Jakarta and Surabaya. Then, it analyses the influence of the international law to the domestic regulation on marine plastic pollution in Indonesia. Results of this research depict the imbalance of international law influence to domestic regulations on marine plastic pollution issues in Indonesia.

KEYWORDS

Marine plastic pollution, legal instruments, international law, domestic law, liability, Indonesia, Jakarta, Surabaya

BACKGROUND

Oceans cover 71% of the Earth's surface, and their vastness is integral to life on Earth. Apart from its role as a principal component in the biosphere, the ocean is also a source of food for the life it helped generate, a bridge for trade and commerce, and a wellspring for adventure and discovery.¹ It directly influences the climate of the planet, the plant and animal world, and evidently the processes of life and human activity.²

Unfortunately, the increase in plastic dependence and uncontrolled developmental activities over the years has resulted in an exacerbation of marine pollution. As defined by the 1982 United Nations Convention on the Law of the Sea ("UNCLOS"), marine pollution is the "introduction by man, directly or indirectly, of substances or energy into the marine environment... which results or is likely to result in such deleterious effects as harm to living resources and marine life." Statistics show that 10 million tons of litter enter the oceans every year,³ and such litter comes from land sources such as rivers, sewage, air and landfills.^{4,5} To make matters worse, this litter contains plastic, a detrimental material. At least 8 million tons of plastic end up in the oceans every year.⁶ The environmental impact of plastic is devastating – 100 million marine animals, more than a million seabirds, and more than 100,000 marine mammals die annually due to plastic pollution.⁷ Plastic pollution is the most widespread problem affecting the marine environment.⁸ The accumulation of plastic in the oceans, and its adverse impact on marine life, has become a global crisis. Three main sources of marine plastic pollution have been identified: direct discharge as effluents and solid wastes from land or human activities at sea, runoff via rivers, and atmospheric fallout.⁹ Amid increasing global concern and public awareness of this crisis, Member States have, one by one, stepped forward to acknowledge that their actions have contributed to this crisis. The UN General Assembly and the UN Environment Assembly (UNEA) have expressed concerns about the pollution of the sea by plastics, which adversely impacts ecosystems, some economic activities (e.g., tourism and fishing), and possibly public health (e.g., consumption of contaminated fish).

Indonesia is one of the main contributors to marine plastic pollution. In 2015, it was the second-largest marine polluter in the world, producing approximately 3.2 million tons of mismanaged trash every year, with close to 1.3 million tons winding up in the sea.¹⁰ Indonesia's unsustainable development has hindered its ability to resolve a plethora of environmental issues and this has ultimately led to marine and coastal pollution in the country. However, in recent years, Indonesia has shown commitment in tackling the problem of pollution and its impacts head-on. Its past achievements include the 2019 ASEAN Coastal Clean Up, and the banning of single-use plastics in Bali. Furthermore, in the recent Our Ocean Conference, Indonesia committed to reduce waste by 30% and to properly manage waste by 70% of total waste generation by 2025. It also budgeted one billion USD to address land-based management of waste.

Nevertheless, beyond the issue of pollution and its impacts, the upstream issue of protection against pollution poses a far greater problem. Although protection of the marine environment can come in many forms, these ultimately rely on legal instruments as the backbone of protection. Over the years, many legal instruments have been developed as a result of better research and understanding of the human impact on the marine environment. However, the question of whether such developments suffice to prevent marine pollution still remains unanswered. As such, this paper raises the question: To what extent do the international legal instruments on marine protection influence domestic regulations on marine plastic pollution? In an attempt to answer this

¹ United Nations, "Oceans and the Law of the Sea" (September 2020), online: UN <<https://www.un.org/en/sections/issues-depth/oceans-and-law-sea/>>.

² Valiulina B. KSENIA, & Adel I. ABDULLIN, "International Legal Regulation of Ocean Pollution Prevention From Land-Based Sources" (2018) 5 The Journal of Social Science Research 149.

³ European Commission, "Our Ocean Factsheet" (September 2020), online; EU <https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/eu-acting-for-our-oceans-factsheet_en.pdf>.

⁴ *Ibid.*

⁵ UNESCO, "Facts and Figures on Marine Pollution" (September 2020), online: UNESCO <<http://www.unesco.org/new/en/natural-sciences/ioc-oceans/focus-areas/rio-20-ocean/blueprint-for-the-future-we-want/marine-pollution/facts-and-figures-on-marine-pollution/>>.

⁶ IUCN, "Issues Brief on Marine Plastics" (September 2020), online: IUCN <<https://www.iucn.org/resources/issues-briefs/marine-plastics>>.

⁷ *Ibid.*

⁸ *Ibid.*

⁹ Dan WILHELMSSON, Richard C. THOMPSON, Katrin HOLMSTORM, Olof LINDEN, and Hanna ERIKSON-HAGG, "Marine Pollution" in Kevin J. NOONE, Ussif Rashid SUMAILA, Robert J. DIAZ, ed., *Managing Ocean Environments in a Changing Climate: Sustainability and Economic Perspectives*, (China: Elsevier, 2013), 127.

¹⁰ Jenna R. JAMBECK, Roland GEYER, Chris WILCOX, Theodore R. SIEGLER, Mirriam PERRYMAN, Anthony ANDRADY, Ramani NARAYAN, Kara Lavender LAW, "Plastic Waste Inputs From Land Into The Ocean" (2015) 347 Science 769.

question, this paper will first highlight the current international laws in place for marine plastic pollution and underlines the issues of international laws influences national law in the marine plastic pollution sector. Next, to address the effect of legal instruments on marine plastic pollution in Indonesia, this paper will give a general outline of key national regulations, and a specific analysis and comparison between two cities in Indonesia: Jakarta and Surabaya. Then this paper concludes with the analysis the influence of the international law to the domestic regulation on marine plastic pollution in Indonesia.

REGULATIONS

International Laws

UNCLOS

Known to be the benchmark, UNCLOS has been ground-breaking in the extension of international law to shared water resources. UNCLOS has resolved issues of ocean usage and sovereignty by establishing freedom-of-navigation rights, setting boundaries, creating the International Seabed Authority, and creating other conflict-resolution mechanisms. In 1972, the United Nations Conference on the Human Environment in Stockholm recommended governments to control marine pollution and monitor and prevent such pollution.¹¹ UNCLOS is the only global instrument that imposes a legally binding obligation upon Member States for the prevention, reduction and control of land-based sources of pollution.¹² The opening provision of Part XII on Protection and Preservation of the Marine Environment, Article 192, provides that “states have the obligation to protect and preserve the marine environment.”¹³ Article 192 is a general provision that covers all types of harm to the marine environment,¹⁴ and specific focus on the prevention of pollution is addressed in further articles. In fact, many of the provisions in Part XII are explicitly concerned with the prevention, reduction and control of pollution of the marine environment.

Article 194 addresses measures to prevent, reduce and control pollution of the marine environment. The provision provides a broad scope and is applicable to all sources of pollution, including classical contaminants,¹⁵ heat and noise.¹⁶ However, the general obligation in Article 194 is insufficient on its own. Rather, it is supplemented by additional rules requiring Member States to implement national rules and standards in tackling marine pollution.¹⁷ This includes pollution from land-based sources,¹⁸ the atmosphere,¹⁹ dumping,²⁰ ships,²¹ seabed activities within national jurisdiction,²² and mining.²³ Therefore, UNCLOS sets not only international obligations, but also national obligations for Member States to incorporate.

Other Notable Instruments

While UNCLOS addresses pollution in general, other notable instruments have elaborated specifically on plastic pollution. These instruments include (a) the International Convention for Prevention of Pollution from Ships (“MARPOL”), (b) the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (“London Convention”) and the 1996 Protocol (London Protocol), and (c) the Convention on Biological Diversity (“CBD”).

¹¹ *Report of the United Nations Conference on the Human Environment*, United Nations Conference on Human Environment, UN Doc A/CONF.48/14/Rev.1 (1972).

¹² *Combating Marine Plastic Litter And Microplastics: An Assessment of The Effectiveness of Relevant International, Regional And Subregional Governance Strategies And Approaches*, United Nations Environment Programme (UNEP), UN Doc. UNEP/AHEG/2018/1/INF/3 (2018).

¹³ *United Nations Convention on the Law of the Sea*, 10 December 1982, art. 192, 1833 U.N.T.S. 397, 21 ILM (entered into force 16 November 1994) [UNCLOS], art. 192.

¹⁴ James HARRISON, *Saving the Oceans through Law: The International Legal Framework for the Protection of the Marine Environment*, (New York: Oxford University Press 2017).

¹⁵ *Ibid.*

¹⁶ Harrison, *supra* note 14.; Harm M. DOTINGA & Alex G. Oude ELFERINK, “Acoustic Pollution in The Oceans: The Search for Legal Standards”, (2000) 31 *Ocean Development & International Law* 151.; Karen N. SCOTT, “International Regulation of Undersea Noise”, (2004) 53 *International and Comparative Law Quarterly* 287.;

¹⁷ Harrison, *supra* note 14..

¹⁸ UNCLOS, *supra* note 13, art. 207.

¹⁹ *Ibid.*, at art. 213.

²⁰ *Ibid.*, at art. 210.

²¹ *Ibid.*, at art. 211.

²² *Ibid.*, at art. 208.

²³ *Ibid.*, at art. 209.

MARPOL

MARPOL serves as the International Maritime Organization's ("IMO") principal convention. It focuses on the prevention of pollution of the marine environment by ships, mainly due to the discharge of harmful substances or effluents.²⁴ In particular, Annex V of MARPOL prohibits the discharge of plastics. In assessing its effectiveness in dealing with sea-based marine litter,²⁵ the IMO, together with the Marine Environment Protection Committee ("MEPC"), reviewed and revised Annex V. The revised Annex V has a broader scope that includes the prohibition of all garbage into the sea, including, inter alia, all types of domestic and operational waste, all plastics, cargo residues and fishing gear.²⁶ Furthermore, plastic mixed with other garbage is to be treated as if it were all plastic, meaning that it would then be subject to stern procedures for handling and discharge.²⁷

London Convention and Protocol

The London Convention and Protocol is another pollution-oriented instrument directed at marine plastic litter and micro plastics from dumping activities of vessels, aircraft, platforms, or other man-made structures at sea. Article 1 of the London Convention and Article 2 of the London Protocol require Parties to "take all practicable steps to prevent the pollution of the sea by the dumping of waste and other matter that is liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea." In 2015, a review was undertaken to evaluate procedures for assessing the litter content of waste streams regulated under the London Convention and Protocol.²⁸ According to the report, micro plastics are most likely contained in dredged material and sewage sludge, and these occasionally include macro plastics as well.²⁹ Despite this high probability, the report found that analysis of litter content is not included as a requirement in current authorization procedures, neither in the waste or at the dump site. Thus, the report proposed that standardized procedures for extracting, identifying and quantifying plastics in sludge and sediments should be a focal area for future studies.

Convention of Biological Diversity (CBD)

Although not directly addressing pollution of the marine environment, another notable convention related to plastic pollution is the CBD. The CBD generally applies to the conservation of biological diversity. Under the CBD, the Aichi Biodiversity Targets were adopted as a set of global targets under the Strategic Plan for Biodiversity 2011-2020. Targets 8 and 10 cover pollution and the ocean and its ecosystem respectively. In support of the Targets, the Parties to the CBD have adopted several relevant decisions, including decision XIII/10. Decision XIII/10 provides voluntary practical guidance on preventing and mitigating the impacts of marine litter on marine and coastal biodiversity.³⁰ Under this decision, Parties, Governments, and international organizations are expected to develop and implement measures, policies and instruments to prevent the discarding, disposal, loss or abandonment of any persistent, manufactured or processed solid material at marine and coastal habitats. In particular, the decision urges Parties to "assess whether different sources of microplastics and different products and processes that include both primary and secondary microplastics are covered by legislation, and strengthen, as appropriate, the existing legal framework so that the necessary measures are applied, including through regulatory and/or incentive measures to eliminate the production of micro plastics that have adverse impacts on marine biodiversity."³¹

It is evident that the CBD encourages the existence of legal frameworks and the application of necessary measures. Against the backdrop of international laws, and with a focus on Indonesia, we now turn to the question of whether, and to what extent, Indonesia has incorporated these international laws at a national level.

²⁴ UNEP, *supra* note 12.

²⁵ *Oceans and The Law of The Sea*, GA Res. 60/30, UN Doc. A/RES/60/30 (2005).

²⁶ UNEP, *supra* note 12.

²⁷ *Ibid.*; *2012 Guidelines For the Implementation of Marpol Annex V*, International Maritime Organization (IMO), Resolution MEPC.219(63) (2012).

²⁸ *Review of the Current State of Knowledge Regarding Marine Litter in Wastes Dumped at Sea under the London Convention and Protocol: Final Report*, International Maritime Organization (IMO), (2016)

²⁹ *Ibid.*

³⁰ UNEP, *supra* note 12.; *Marine And Coastal Biodiversity: Sustainable Fisheries And Addressing Adverse Impacts Of Human Activities, Voluntary Guidelines For Environmental Assessment, And Marine Spatial Planning*, Conference of Parties to the Convention of Biological Diversity (COP-CBD), Disrt. General IX/18, UN.Doc UNEP/CBD/COP/DEC/XI/18 (2012).

³¹ *Addressing Impacts of Marine Debris And Anthropogenic Underwater Noise on Marine Coastal Biodiversity*, Conference of Parties to the Convention of Biological Diversity (COP-CBD, Disrt. General XIII/10, UN. Doc. CBD/COP/DEC/XIII/10 (2016).

The Issues of International Law's Influence on Domestic Law in Marine Plastic Pollution

The Application of International Law into Domestic Law

Classic theories of International Law stated that international law binds states, international organizations, non-State entities such as multinational enterprises or non-governmental organizations, and individuals.³² Therefore, domestic laws should be in conformation with international law and so domestic laws' legislatures cannot breach international obligations when producing laws³³ to create a harmony of laws. However, in practice, domestic laws have become the footings of international law, providing dynamics and room to exist, grow, and flourished to the international law we have today.

'Monist' argues that international law is no different legal order than domestic law. It argues that international law stands taller than domestic law, which means international law always prevails even if there any conflicts of law between international law and domestic law.³⁴ International law automatically becomes binding by way of incorporating it into the domestic law.³⁵ In Hans Kelsen's *Stuffenbau*, international law is always superior to domestic law.³⁶ However, not all treaties can directly be incorporated into the domestic law automatically, and so some treaties need implementing laws.

On the other hand, 'Dualist' argues that international law and national law are not on the same level of legal order. Consequently, it is a matter of fact that international law cannot be automatically implemented at a national level, for the States need to pick and choose which treaties they want to enforce.³⁷ International law must be converted into domestic law. However, in international tribunals, international law will always prevail.³⁸ Still, international law and domestic law are independent from each other and needs an authorization from the respective state to be able to enforce international law in its domestic legal system.³⁹

Indonesia has been a State which uses both theories interchangeably. This is due to the fact that the definition of treaty/international agreement is unclear, and the legal system has not provided clear definition and legal concept of ratification.⁴⁰ The Law No. 24 of 2000 need to adjust its provisions with the provisions of the Vienna Convention on the Law of Treaties 1969 and 1986, to provide clear regulation regarding the hierarchy and status of treaty/international agreement as well as its implementation.⁴¹

International Law Influence to Domestic Law

Threats of Globalizations and disruptions have brought the world into a different setting. Examples of these threats are terrorism, COVID-19 pandemic, money laundering, trafficking, refugee problems, and transboundary pollution such as the marine plastic pollution. These are international problems which have domestic roots that an interstate legal system is often powerless to address.⁴² To offer an effective response to these new challenges, the international legal system must be able to influence the domestic policies of states and harness national institutions in pursuit of global objectives.⁴³

Burke-White and Slaughter argued that the functions of international law has expanded towards influencing domestic institutions. Due to the many abovementioned threats, and to create desirable conditions in the international system, international law must

³² Illias BANTEKAS and Efthymios PAPASTAVRIDIS, *International Law Concentrate: Law Revision and Study Guide*, 3rd eds, (New York: Oxford University Press, 2017) at 3.

³³ ANTHONY Mason, "The Relationship between International Law and National Law, and Its Application in National Courts" (1992) 18 Commonwealth Law Bulletin 750 at 752.

³⁴ Bantekas and Papastavridis, *supra* note 37 at 48

³⁵ Visar MORINA, Fisnik KORENICA, and Dren DOLI, "The Relationship Between International Law And National Law In The Case Of Kosovo: A Constitutional Perspective" (2011) 9 International Journal of Constitutional Law 274 at 280.

³⁶ CHIAM Madelaine, "Monism and Dualism in International Law" *Oxford Bibliographies Online Datasets*, (25 May 2020), online: Oxford Bibliographies Online Datasets <<https://www.oxfordbibliographies.com/view/document/obo-9780199796953/obo-9780199796953-0168.xml>>.

³⁷ Bantekas and Papastavridis, *supra* note 37.

³⁸ Morina, Korenica, and Doli, *supra* note 40.

³⁹ Chiam, *supra* note 41.

⁴⁰ Eddy PRATOMO and R Benny RIYANTO, "The Legal Status of Treaty/international Agreement and Ratification in the Indonesian Practice Within the Framework of the Development of the National Legal System" (2018) 21 Journal of Legal, Ethical and Regulatory Issues.

⁴¹ *Ibid.*

⁴² William W BURKE-WHITE and Anne-Marie SLAUGHTER, "The Future of International Law is Domestic (or, The European Way of Law)" (2006) 7 Harvard International Law Journal 327.

⁴³ *Ibid.*

address the capacity and the will of domestic governments to respond to these issues at their sources.⁴⁴ These are done through strengthening domestic institution, backstopping them, and compelling them to act accordingly to international law.⁴⁵

This study elaborates how international law instruments in the marine plastic pollution sector influence the domestic governments in Indonesia. The following sections will elaborate how international law instruments strengthening domestic institution, backstopping and compelling the government to act.

Marine Plastic Pollution Issues in International Law

Marine plastic pollution rule of law is about changing the mind set and introducing eco-friendly alternative materials to replace single use plastics. We have been relying on plastics (especially the single use plastics) because they are ‘cheap, safe, and simple’. This mind set needs to change because single use plastics are not cheap, safe and simple, especially since they are not recyclable. Let us think of the amount of time plastic takes to biodegrade and become part of our natural environment, which ranges from 60-500 years⁴⁶. Estimates suggest that we only recycle 9% of waste plastic, and 12% is incinerated⁴⁷. The rest ends up in landfills or in our environment, including the oceans⁴⁸. Imagine the price we pay for the impact of those plastics staying in our environment for 500 years, including the health costs from that plastic waste to our environment; in land, on the ocean and marine life. Marine plastic pollution rule of law is about changing the mind set and introducing eco-friendly alternative materials to replace single use plastics.

The complication in marine plastic pollution rule of law is to determine liability and compensation. Liability means being legally responsible for something, in the case: pollution. In the case of marine plastic pollution, the “Polluter-pays principle”⁴⁹ appears to be the clear cut answer, but it poses questions in terms of liability. The principle takes place when an activity affects society at large, and it is only fair for this “cost” to be assumed by the one benefitting from the activity. Complications for marine plastic pollution is to determine who benefits from disposing of plastic waste into the ocean. Marine plastic pollution arises from many land-based and ocean-based sources, scattered across the jurisdiction of many states. S Maljean-Dubois and B Mayer (2020) stated that liability can also be imposed on corporations that produce plastic, on those who provide it to consumers, on consumers themselves, or even on those who dispose of plastic waste in the environment, and states. A liability regime focused on compensation would not be an appropriate solution to marine plastic pollution because of the difficulties in determining the recipient for the compensation.⁵⁰

W.C. Li et al (2016) stated that the main evidence for marine plastic pollution are its ecological impacts,⁵¹ which also can spread to multiple jurisdictions. The UNCLOS (1982) and other treaties require states to prevent, reduce, and control the discharge of pollutants into the marine environment including plastics. Marine plastic pollution may result from breaches of international law obligations, and this is attributable to States. This means that the State Responsibility principle is applicable in the marine plastic pollution cases. The Trail-Smelter Case (1941) stated that State Responsibility requires a wrongful act attributable to state, and transboundary harm to occur. Similar principles articulated by the declarations from the United Nations Conference on the Human Environment (Stockholm Declaration 1972) and the United Nations Conference on Environment and Development (Rio Declaration 1992).

The question here is which state/s this occurs when the plastic debris are floating all over the earth’s ocean? The possible answer is *all states*. Environmental restoration, for example, is more suitable solution for marine plastic pollution, rather than focusing on the liability as it is too diffused to be determined.

⁴⁴ *Ibid.*

⁴⁵ *Ibid.*

⁴⁶ “The Lifecycle of Plastics” *WWF* (19 June 2018), online: WWF <<https://www.wwf.org.au/news/blogs/the-lifecycle-of-plastics#gs.m9qpds>>.

⁴⁷ *Ibid.*

⁴⁸ PARKER Laura, “We Made Plastic. We Depend on It. Now We’re Drowning in It” *National Geographic*(June 2018), online: National Geographic <<https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/>>.

⁴⁹ Sandrine MALJEAN-DUBOIS and Benoît MAYER, “Liability and Compensation for Marine Plastic Pollution: Conceptual Issues and Possible Ways Forward” (2020) 114 *American Journal of International Law Unbound* 206.

⁵⁰ *Ibid.*

⁵¹ W. C. LI, H. F. TSE, and L. FOK, “Plastic Waste in the Marine Environment: A Review of Sources, Occurrence and Effects”, (2016)566-567 *Science of Total Environment* 333.

On the other hand, if liability were to be pinned to non-state sources, private international environmental law allows for actions between non-state actors, with civil actions such as nuisance torts allowing potential remedies for individuals or class-actions involving groups of individuals against polluters residing in another state.

The real implementation of reducing marine plastic pollution will be in the national and local levels where people are handling plastic waste firsthand, from extraction, production, fabrication, use/reuse, to disposal as waste. Many provinces and districts in Asian countries are still out of touch on how to curb marine plastic pollution. International or regional legal frameworks on marine plastic pollution's function is to strengthen and motivate national governments to encourage their regional/local governments, and stakeholders, to adopt measures to curb marine plastic pollution, backstopping and compelling them to take action in reducing marine plastic pollution, as will be discuss in the following sections.

Indonesian Laws and Regulations on Marine Plastic Pollution

International laws prove insufficient without Member States subsequently incorporating and implementing them into national laws and regulations. During the 2017 Leaders' Retreat, G20 Summit in Hamburg, Germany, and the 2018 Our Ocean Conference in Bali, President Joko Widodo declared that the Government of Indonesia would commit to reducing waste by 30%, handling waste by 70%, and reducing plastic waste entering the sea by 70% by 2025. Meanwhile, in a recent report on the release of land-derived marine debris in Greater Jakarta,⁵² plastics were the "single most dominant debris entering Jakarta Bay."⁵³ An estimated 2,323 tons of debris is released into Jakarta Bay daily.⁵⁴ Putting this into perspective, comparisons will be made between these statistics and the existence of laws in cities in Indonesia, focusing on regional laws, governor regulations, and mayor's regulations. In doing so, possible correlations can be deduced from the laws and the facts.

Thus, as this paper seeks to examine the effectiveness of legal instruments on marine protection, in particular, its effect on marine plastic pollution debris, closer analysis and comparison will be made between (1) national regulations, (2) regulations in Jakarta and (3) regulations in Surabaya.

National Regulations

Laws (Undang-Undang)

Law No. 32 Year 2014 ("Law No. 32/2014"), concerning the Sea, and Law No. 32 Year 2009 ("Law No. 32/2009"), concerning the Protection and Management of the Environment, are two key Indonesian laws that aim to better protect its oceans.

Law No. 32 Year 2014

The definition of marine protection and prevention of marine pollution is similar to that provided in UNCLOS – Indonesia recognizes that the protection of the marine environment includes the prevention and control of pollution. Particularly, in Article 1(11) of Law No. 32/2014, Indonesia defines marine pollution as "[the] entering or inclusion of a living being, substance, energy, and/or other components into the sea environment by human activities that exceed the marine environmental quality standards established."⁵⁵ Pollution is mentioned throughout Law No. 32/2014, and is elaborated upon in Article 52.⁵⁶ However, on the whole, Law No. 32/2014 only briefly mentions pollution prevention,⁵⁷ management,⁵⁸ and control;⁵⁹ it does not include specific mention of marine plastic pollution.

⁵² Muhammad Reza CORDOVA and Intan Suci NURHATI, "Major Sources And Monthly Variations in The Release of Land-Derived Marine Debris From The Greater Jakarta Area, Indonesia", (2019) 9 Scientific Reports 18730.

⁵³ *Ibid.*

⁵⁴ *Ibid.*

⁵⁵ Indonesia Law No. 32 Year 2014, art. 1(11).

⁵⁶ *Ibid.*, at art. 52.

⁵⁷ *Ibid.*, at art. 11.

⁵⁸ *Ibid.*, at art. 52(4).

⁵⁹ *Ibid.*, at art. 50.

Although Law No. 32/2014 provides a general understanding, it obliges both the central and local government to “implement a system of prevention and mitigation of pollution and marine environmental damage.”⁶⁰ Pollution protection thus extends beyond the federal level, and must be elaborated and systemized in accordance with local governments. The government is responsible for achieving this,⁶¹ and is encouraged to work together bilaterally, regionally and multilaterally.⁶²

Law No. 32 Year 2009

Law No. 32 Year 2009 concerns the Protection and Management of the Environment, and is the overarching law to combat pollution. It covers matters relating to pollution sources, management, sanctions, duties and authorities of the government, local government and the people. The marine environment is only mentioned in Article 63(1)(1), which provides that the Government’s duties and authorities include developing and implementing “policies on the protection of the marine environment.”⁶³ However, Law No. 32/2009 lacks detail on plastic pollution and, more specifically, marine plastic pollution. Similar to Law No. 32/2014, Law No. 32/2009 reinforces and highlights the role of the Government in regulating the protection of the marine environment.

Presidential Decrees

As a follow-up to the Government’s commitment to reduce plastic waste at sea by 70% by 2025, Presidential Decree No. 83 Year 2018, concerning Sea Waste Management, was enacted. The Decree recognizes the existence of plastics in the biota and marine resources, as well as its difficulty in decomposing.⁶⁴ As such, the Decree established the National Action Plan for Handling Marine Waste for 2018-2025 (“National Action Plan”). The National Action Plan utilizes “synergistic, measurable, and directed strategies, programs and activities”⁶⁵ as a means to reduce the amount of waste in the sea, especially plastic waste. It directs government ministries and institutions to accelerate the management of marine waste.⁶⁶

The National Action Plan uses a three-pronged approach to handle marine plastic debris. First, coordination between institutions responsible for waste management, second, application of technology to control plastic debris, and third, societal efforts to reduce, recycle and reuse plastic debris. This approach is founded upon five main pillars, which include improving behavioral change, reducing land-based leakage, reducing sea-based leakage, reducing plastics production and use, and enhancing funding mechanisms, policy reform, and law enforcement.

However, although partial national regulations are in place, the effectiveness of these laws depend, in turn, on the effectiveness of local laws.

Regulations in Jakarta

Jakarta is one of the world’s largest cities, the biggest city by a wide margin in Southeast Asia, and the commanding urban center of Indonesia, the world’s second most populous city after Tokyo. At the same time, the city aspires for recognition in its Asian region and the world more widely as an emerging leader among the world’s great metropolises. Jakarta is located at the northern tip of Java Island, directly on the coast of Java Sea connected to the Jakarta bay area.

To determine the extent of local participation in combating marine plastic pollution, an assessment on the role of (a) regional regulations, and (b) governor regulations will be conducted. Notably, no mayor regulations are currently in place for handling plastic pollution.

Regional Regulations

Regional Regulation of the Special Capital Province of Jakarta No. 3 Year 2013 Concerning Waste Management addresses waste management, administration, collection, and sanctions. The Regulation aids in preventing air, land, and water pollution by

⁶⁰ *Ibid.*, at art. 55.

⁶¹ *Ibid.*, at art. 56(1).

⁶² *Ibid.*, at art. 56(2).

⁶³ Indonesia Law No. 32 Year 2009, art. 63(1)(1).

⁶⁴ Indonesia Presidential Decree No. 83 Year 2018, Preamble.

⁶⁵ *Ibid.*, at art. 2(1).

⁶⁶ *Ibid.*, at art. 2(2).

mentioning it as a prohibited act by the people,⁶⁷ as a negative impact of mismanaged waste,⁶⁸ and by way of sanctions.⁶⁹ However, apart from the brief mention of plastic bags,⁷⁰ goggles,⁷¹ and head protection gear in the elaboration to various Articles,⁷² there is no explicit article that addresses the problem of plastic waste. Nevertheless, another possible component from this regulation that aids in reducing marine plastic pollution is its function in educating the people to stop littering in rivers. However, it is evident that the regulation lacks details on marine plastic pollution and merely addresses waste issues in general.

Governor Regulations

Jakarta has minimal governor regulations that address marine plastic pollution. While a targeted regulation is non-existent, there are two related regulations that target water pollution and plastic bags respectively. These are the Governor Regulation of the Special Capital Province of Jakarta No. 122 Year 2005 on Domestic Waste Water Management (“*Pergub* No. 122 Year 2005”),⁷³ and the Governor Regulation of the Special Capital Province of Jakarta No. 142 Year 2019 on the Obligation to Use Environmentally Friendly Shopping Bags at Shopping Centers, Convenience Stores, and Public Markets (“*Pergub* No. 142 Year 2019”).⁷⁴ *Pergub* No. 122 Year 2005 focuses on the prevention and management of soil and groundwater pollution. Although it does not mention marine pollution, its processes indirectly affect waterways. In contrast, *Pergub* No. 142 Year 2019 directly addresses marine pollution by prohibiting the use of single-use plastic bags. Governor Anies Baswedan, who was possibly motivated by the copious amount of pictures in the media depicting floating plastic bags in the ocean, enacted the law as a means to prevent and reduce the number of plastic bags from ending up in the ocean. Instead, eco-friendly shopping bags are encouraged as an alternative. However, despite its good intentions, the regulation has received some negative feedback. It has been criticized for its insufficiency in handling other forms of plastic that are equally detrimental to the marine environment, such as straws or Styrofoam. Moreover, based on the report on plastic debris in the Greater Jakarta region, Styrofoam constitutes one of the biggest components in plastic waste. Hence, though steps have been made in the right direction, the efficiency and effectiveness of these steps remain questionable, especially since they fail to encompass other major components of plastic waste.

Regulations in Surabaya

Surabaya is the capital city and a port city of East Java. The coastal area is well known to numerous communities and is a tourist hotspot. Current population of Surabaya is 2,853,661.⁷⁵ Surabaya is one of the cities in Indonesia which managed to clean its environment and increased its’ living conditions. The former mayor of Surabaya, Tri Rismaharini was awarded as the 2nd Runner Up of World’s Best Mayor 2015, as well as recognized as one of the World’s 50 greatest leaders by Fortune Magazine. The city, long known for pollution and congestion, now boasts 11 richly landscaped parks and other green spaces. In some cases even cemeteries have been expanded and redesigned to absorb more water and reduce flooding, an ever present risk in Indonesia. In the geographic and demographic context, the popularity of this coastal area has had negative impacts on its marine environment.

A study entitled Plastic debris in sediments from the east coast of Surabaya, was jointly conducted by the Environmental Engineering departments from Chung Yuan Christian University and Adhi Tama Institute of Technology Surabaya to assess the prevalence of plastic debris in Surabaya.⁷⁶ The report identified Bulak as a major district with the highest incidence of plastic debris, followed by the districts of Kenjeran, Gunung Anyar and Rungkut.

With the understanding that rapid urbanization has increased Surabaya’s susceptibility to marine pollution, it is important to analyze the regulations in preventing and managing the impacts of marine pollution. As such, (a) regional regulations, and (b) governor regulations and mayor regulations will be analyzed.

⁶⁷ Regional Regulation of the Special Capital Province of Jakarta No. 3 Year 2013, art. 126.

⁶⁸ *Ibid.*, at art. 106(2)(a).

⁶⁹ *Ibid.*, at art. 134.

⁷⁰ Elaboration of art. 6(2)(b), and art. 19(1)(b).

⁷¹ Elaboration of art. 81(2)(b).

⁷² Elaboration of art. 81(2)(a).

⁷³ Governor Regulation of the Special Capital Province of Jakarta No. 122 Year 2005.

⁷⁴ Governor Regulation of the Special Capital Province of Jakarta No. 142 Year 2019.

⁷⁵ “City Dashboard Surabaya” *Global Covenant of Mayors for Climate & Energy* (18 February 2021) online: Global Covenant of Mayors for Climate & Energy <<https://www.globalcovenantofmayors.org/cities/southeast-asia/indonesia/surabaya/>>.

⁷⁶ A C Ni’am, S J You, Y F Wang and J J Jiang, “Plastic Debris in Sediments From The East Coast of Surabaya”, (2019) 462 IOP Conference Series: Materials Science and Engineering 012050.

Regional Regulations

Surabaya has several regional regulations in place that particularly relate to land-based pollution. These include the Regional Regulation of Surabaya City No. 12 Year 2016 concerning Water Quality Management and Waste Control (“Perda No. 12 Year 2016”) and the Regional Regulation of Surabaya City No. 5 Year 2014 (“Perda No. 5 Year 2014”) concerning Waste Management and Cleanliness in Surabaya City. Both regulations address pollution caused by waste that may eventually be deposited into the oceans, with one focusing on household waste and the other on wastewater. The regulations focus on the management and general prevention of pollution to the environment.

However, neither regulation addresses marine plastic pollution specifically. *Perda* No. 5 Year 2014, and the following Regional Regulation of Surabaya City No. 1 Year 2019 (“*Perda* No. 1 Year 2019”), only mentions the reduction of the use of plastic bags, and *Perda* No. 12 Year 2016 focuses instead on the management of quality water for sustainability,⁷⁷ and the restoration and management of wastewater as a means to prevent water pollution and encourage recovery.⁷⁸ *Perda* No. 12 Year 2016 is slightly relevant as it concerns waste discharge at water sources. However, the mere mention of water sources, without any links drawn between the wastewater components and its risk to the oceans, is insufficient for the purpose of preventing marine plastic pollution.

Governor and Mayor Regulations

Governor regulations of the East Java Province relating to marine plastic pollution are mostly broad and focus on land-based pollution, in particular, pollution from business or industrial activities.⁷⁹ Both the Governor Regulation No. 10 Year 2009 concerning Ambient Air Quality Standards and Stationary Emission Sources in East Java, and the Governor Regulation No. 72 Year 2013 j.o. No. 52 Year 2014 Quality Standards for Wastewater for Industry and/or Business Activities in East Java, do not address plastic pollution specifically in terms of wastewater.

As for Mayor Regulations, overall environmental protection in Surabaya is enforced,⁸⁰ but regulations on marine plastic pollution are still lacking.

International Law Influence to Indonesia’s Domestic Law in Marine Plastic Pollution

In the case marine plastic pollution in Indonesia, we have seen that the current international instruments are not completely focused and have loopholes on the marine plastic pollution issues. UNCLOS (1982) in its Article 194 on pollution does not mention marine as a target area, MARPOL in its Annex V grouping all garbage in the sea, including domestic and operational waste plastic. The CBD does not directly address pollution of the marine environment, and The London Convention and Protocol even though it includes marine plastic and micro plastic, but it does not include litter content in waste streams (dredge materials and sewage sludge where micro plastic are usually found).

However, these instruments are already ratified and adopted by Indonesia, and should have some influence in Indonesia. Burke-White and Slaughter argued that the functions of international law has expanded towards influencing domestic institutions. This include three things: strengthening domestic institution, backstopping them, and compelling them to act accordingly to international law.⁸¹

Strengthening Domestic Institution in Indonesia’s Marine Plastic Pollution

The limited capacity of domestic institution is the primary hurdle in international system. In the case of marine plastic pollution there are many of global networks established by the international community to help connect the aptitude of governments. Among others, Indonesia has joined the networks of Group of 20 (G20), and the Coordinating Body on the Seas of East Asia (“COBSEA”). Both networks have elevated Indonesia’s effort in strengthening domestic institutions in providing technical assistance, setting benchmarks and standards, and/or encouraging other forms of cooperation.

⁷⁷ Regional Regulation of Surabaya No. 12 Year 2016, art. 2(1).

⁷⁸ *Ibid.*, at art. 2(2); Governor Regulation of East Java No. 10 Year 2009.

⁷⁹ Governor Regulation of East Java No. 10 Year 2009.

⁸⁰ Mayor Regulation of Surabaya No. 26 Year 2010.; Mayor Regulation of Surabaya No. 66 Year 2015.; Mayor Regulation of Surabaya No. 74 Year 2016.

⁸¹ *Ibid.*

In 2017, the G20 adopted an Action Plan on Marine Litter, pledging to “take action to prevent and reduce marine litter of all kinds, including from single-use plastics and micro-plastics”.⁸² The Action Plan also launched a voluntary Global Network of the Committed, a platform for information exchange that is linked to the UNEP Global Partnership on Marine Litter.⁸³ Notably, Indonesia is the only ASEAN country in the G20.

The revised COBSEA Regional Action Plan on Marine Litter was adopted in 2019 at the 24th Intergovernmental Meeting of COBSEA in Bali, Indonesia.⁸⁴ The Action Plan applies to the countries participating in the East Asian Seas Action Plan – with the exception of Brunei, Laos and Myanmar, all ASEAN countries are members of COBSEA. This Action Plan comprises four main actions: preventing and reducing marine litter from land-based and sea-based sources, monitoring and assessment of marine litter, and activities supporting the implementation of the Action Plan itself.⁸⁵

Backstopping and Compelling Action by Domestic Government in Indonesia’s Marine Plastic Pollution

International law can also function as backstopping and compelling action by domestic government.⁸⁶ The idea is not a new one, traditionally international law is seen as a backstop when national law fails to act as first mean of prosecution.⁸⁷ In the marine plastic pollution issues, because liability and prosecution are still much diffused, countries have grouped together and provide themselves with ‘strategic plans’ or ‘plans for actions’. Within these institutions and instruments, countries are gearing themselves to implement and execute actions and commitments toward elimination of marine plastic pollution. Towards these goals, Indonesia has formed and joined The CTI-CFF Regional Plan of Action (“RPOA”) and PEMSEA adopted the Sustainable Development Strategy for the Seas of East Asia Implementation Plan (“SDS-SEA 2003”).

The CTI-CFF Regional Plan of Action (“RPOA”) was adopted on 15 May 2009 in Manado, Indonesia under the CTI Leaders’ Declaration.⁸⁸ Among the ten ASEAN countries, only Indonesia, Malaysia and Philippines are involved in the RPOA, which seeks to conserve and sustainably manage coastal and marine resources within the Coral Triangle region. The first RPOA recently concluded in 2019, and the second iteration of the RPOA is currently under development.⁸⁹

In 2003, under the Putrajaya Declaration, the members of PEMSEA adopted the Sustainable Development Strategy for the Seas of East Asia Implementation Plan (“SDS-SEA 2003”), a plan geared towards sustainable development of the oceans and coasts in the region. Subsequently, under the 2015 Danang Compact, an updated version of the SDS-SEA 2003 (“SDS-SEA 2015”) was adopted with four main targets, including the target of introducing national coastal and ocean policies and supporting legislation in all PEMSEA countries by 2021.⁹⁰ To achieve these targets, SDS-SEA Implementation Plans are to be adopted at both regional and national levels. Furthermore, in the 2018 Iloilo Ministerial Declaration, PEMSEA countries have specifically pledged to “reducing or preventing marine pollution of all kinds, in particular from land-based and sea-based activities, including marine litter and nutrient pollution.”⁹¹ The ASEAN countries in PEMSEA include Cambodia, Indonesia, Laos, Philippines, Singapore, and Vietnam.

As can be seen in the previous deliberation, Indonesia in the national level has clearly been influenced by international law of marine plastic pollution. The fact that Indonesia has built, developed, and joined networks on the avoidance and management of marine plastic pollution for technology transfer, benchmarking, trainings, and building strategic and action plans shown how the international instruments of marine plastic instrument has strengthened, backstopped, and called the domestic government to action.

⁸² G20 Hamburg 2017, “Action Plan on Marine Litter” (18 September 2020), online: G20 Hamburg 2017 <<https://www.mofa.go.jp/mofaj/files/000272290.pdf>>.

⁸³ *Ibid.*

⁸⁴ Coordinating Body on the Seas of East Asia, “Regional Action Plan on Marine Litter 2019” (18 September 2020), online: COBSEA <<https://www.unenvironment.org/cobsea/resources/policy-and-strategy/cobsea-regional-action-plan-marine-litter-2019>>.

⁸⁵ *Ibid.*

⁸⁶ Burke-White and Slaughter, *supra* note 47.

⁸⁷ See 1998 Rome Statute of International Criminal Court, 17 July 1998, 2187 U.N.T.S 90, 37, ILM 1002 (entered into force 1 July 2002) [Rome Statute], art. 17 Rome Statute, states that ICC can step in and provide second line of defense in cases where domestic institutions fail “due to a total or substantial collapse or unavailability of its national judicial system,” or where a state is unwilling to prosecute “independently or impartially.”

⁸⁸ Coral Triangle Initiative, “Coral Triangle Initiative Leaders’ Declaration on Coral Reefs, Fisheries and Food Security” (18 September 2020), online: Coral Triangle Initiative <https://coraltriangleinitiative.org/sites/default/files/resources/Leader%20Declaration%20coral%20triangle%20initiative_0.pdf>.

⁸⁹ Coral Triangle Initiative, “Joint Ministerial Statement The 7th CTI-CFF Ministerial Meeting (MM-7)” (18 September 2020), online: Coral Triangle Initiative <<http://www.coraltriangleinitiative.org/news/joint-ministerial-statement-7th-cti-cff-ministerial-meeting-mm-7>>.

⁹⁰ PEMSEA, “Da Nang Compact on the Sustainable Development Strategy for the Seas of East Asia 2015” (18 September 2020), online: PEMSEA <<https://pemsea.org/sites/default/files/Danang%20Compact%202015.pdf>>.

⁹¹ PEMSEA, “Iloilo Ministerial Declaration” (18 September 2018), online: PEMSEA <http://pemsea.org/sites/default/files/Iloilo_Ministerial_Declaration.pdf>.

However, as we seen in the Jakarta and Surabaya’s case, even though these cities are among the largest ones, most developed, and arguably most exposed to international law in Indonesia, influence of marine plastic pollution international instruments has not trickled down to the local levels. Most pollution regulations in place are land-based. Jakarta has a governor’s regulation on plastic ban, but the regulation is silent on marine plastic pollution. Surabaya calls itself as an eco-coastal city, but yet as an eco-coastal city it still does not have any regulations on marine plastic pollution.

CONCLUSION

Although protection of the marine environment can come in many forms, these ultimately rely on legal instruments as the backbone of protection. This study concludes several important points in the marine plastic pollution international law instruments influence to domestic law and governance.

First, the international legal instruments need to be able to drive the community to change their mind set on plastic, specifically the single use plastic. From a mind-set of the single use plastic as a ‘cheap-clean-and easy’ everyday item to a mind-set that understood the life cycle of plastic, from resource extraction, until the post-use of plastic which is very costly and burdensome for the environment. An example of this would be the protection for the ozone layer through Montreal Protocol (1987).⁹² This global action successfully eliminate substances which depletes the earth’s ozone layer after 30 years, through many efforts, evidently changing the mind set of people to depart from production and consumption of ozone depleting substances and introducing environmentally safe substances technology.⁹³

Second, the complication of liability and compensation in marine plastic pollution. Complications for marine plastic pollution is to determine who benefits from disposing of plastic waste into the ocean. Marine plastic pollution arises from many land-based and ocean-based sources, scattered across the jurisdiction of many states. A liability regime focused on compensation would not be an appropriate solution to marine plastic pollution because of the difficulties in determining the recipient for the compensation⁹⁴. Environmental restoration, for example, is more suitable solution for marine plastic pollution, rather than focusing on the liability as it is too diffused to be determined.

Third, international law on marine plastic pollution’s influence on Indonesia’s domestic law can be seen in the national level. This is seen in the activities of the government of Indonesia in marine plastic pollution global networks, such as G20, COBSEA, CTI-CCF Regional Plan of Action, and PEMSEA SDS-SEA. The influence of international law as *strengthening the domestic governance* in the issue is shown by the fact that these networks provides information, technology transfers, training for the member countries. They also learn from each other by providing benchmarks and lesson learned from one another. Moreover, international law is also influencing Indonesia through these networks in *backstopping and compelling the government to take necessary actions* in the marine plastic pollution issue, through the development of action/strategic plan development, collaborative research, as well as capacity building activities.

Fourth, there is a lack of awareness of the local institutions toward marine plastic pollution issues in the local level, specifically in the case study areas of Jakarta and Surabaya. The international law’s influences we saw in the national level, have not trickled down to the local level. We have seen a highly inadequate legal instruments correlate with high plastic pollution debris. These might be due to the difficulty in implementation of such international legal instrument, because of lack of capacity and resources, and because of marine plastic pollution issues are not put as priorities in the domestic level of developing countries such as Indonesia, specifically in the local levels. Both Jakarta and Surabaya have high levels of marine plastic pollution debris, and neither city has stringent and adequate laws to prevent and manage such pollution. Most laws in place deal with land-based sources, focusing on overall environmental protection while neglecting targeted protection on the marine environment. It is the government’s and stakeholders’ responsibilities to make sure that the marine plastic pollution issue is prioritized in the local levels.

⁹² United Nations Environment Program, “About Montreal Protocol” (5 April 2021), online: UNEP <<https://www.unenvironment.org/ozonaction/who-we-are/about-montreal-protocol>>.

⁹³ *Ibid*

⁹⁴ Maljean-Dubois and Mayer, *supra* note 54.

Additionally, there is an imbalance between the international, national, and local laws. The international laws are sufficiently clear and progressive in its efforts to address the rapidly growing concerns of marine plastic pollution and its prevention. Member States have the obligation to further incorporate such laws into national legislation. Indonesia has clearly recognized the pressing need to protect the marine environment from plastic pollution, as evidenced by President Widodo's statement and the subsequent laws that were enacted as a follow-up. However, there is an obvious lack of further follow-ups, as evinced by the minimal efforts taken to shape local laws to conform to international and national laws.

Furthermore, while correlations are evident in Jakarta and Surabaya, a causal relationship cannot be established yet, and further studies and reports are required to confirm causality. Nevertheless, the correlation highlights the need for more laws and regulations on marine plastic pollution to be set in place. A narrow focus on land-based sources does not suffice, and a more holistic approach must be taken for optimal protection and prevention.

Lastly, what can be arranged for marine plastic pollution rule of law? As a comparison, in the climate change regime, the Paris Agreement (2015) doesn't involve or provide a basis for any liability or compensation, but aims more at enhancing knowledge and coordination, action and support, including finance, technology and capacity-building, to address loss and damage.⁹⁵ This example of creating a new regulatory framework through treaty obligations might be the most applicable framework for the marine plastic pollution regime.⁹⁶ States are to regulate plastic from the upstream – downstream, from curbing production to handling consumption, and up to plastic waste management.

The real implementation of reducing marine plastic pollution will be in the national and local levels where people are handling plastic waste firsthand, from extraction, production, fabrication, use/reuse, to disposal as waste. Many provinces and districts in Asian countries are still out of touch on how to curb marine plastic pollution.⁹⁷ International or regional legal frameworks on marine plastic pollution will motivate national governments to encourage their regional/local governments, and stakeholders, to adopt measures to curb marine plastic pollution.

⁹⁵ United Nations Framework Convention on Climate Change, "The Paris Agreement" (5 April 2021), online: UNFCCC <<https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>>.

⁹⁶ Maljean-Dubois and Mayer, *supra* note 54.

⁹⁷ DOMINIC Faulder, "Asia Plastic Is Choking The World's Oceans" *Nikkei Asia* (5 April 2021), online: Nikkei Asia <<https://asia.nikkei.com/Spotlight/The-Big-Story/Asian-plastic-is-choking-the-world-s-oceans>>.

MODELING THE EFFECTS OF NATURE-BASED SOLUTIONS (NBS) ON URBAN AIR QUALITY USING CFD MODEL PALM4U

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Environ

ABSTRACT

This study investigates the effects of a green space in one of the most polluted areas of the Madrid (Spain) city for a week of June 2017. The PALM4U (BMBF, DE) computational fluid dynamics (CFD), which includes aerodynamics, energy fluxes, chemical and deposition effects, was used to simulate pollutant dispersion for different scenarios, under real morphological and micrometeorological environment with very high spatial resolution (5 m). The simulated scenarios are: BAU (Business as Usual) scenario where broadleaf trees are the dominant tree type. The second scenario is focused on changing the type of the tree from broad leaf at BAU scenario to needle leaf the so-called ND scenario and the third scenario called NOTREE which comprise the replacement of the trees located in the green zone. Meteorological and chemical initial and boundary conditions are supplied by a WRF/Chem (NCAR, US) simulation up to 1 km of spatial resolution. The analysis shows that the trees area has non uniform effects (positive and negative) on the concentrations of pollutants (NO_2 and O_3) over all computational domain, 1 km by 1km. The simulations show that trees have direct effects on air pollution (emission and deposition) and indirect effects to change the microclimate (energy fluxes, temperature, ventilation). The applied modelling tool can be used to evaluate the effect of Nature Base Solution (NBS) before to apply them because the PALM4U simulation reproduce successfully pollutant dispersion taking into account the real building morphology, water green areas.

KEYWORDS

PALM4U, NBS, biogenic emissions, air quality

INTRODUCTION

Urban vegetation is an important element influencing the dispersion of pollutants in the cities. In fact, the impacts of vegetation in urban areas and its application as a mitigation measure for urban air pollution is currently under discussion. This work tries to supply new scientist data to the urban air quality community. The motivation is related to the complex processes that make it difficult to extract general conclusions due to the high dependence on local conditions. Several modelling techniques, especially through Computational Fluid Dynamics (CFD), models are being applied to study the impact of urban vegetation on pollutant dispersion [1]. The impact of vegetation is produced by the aerodynamic effect, altering fluxes, and by the emission and deposition process, adding and removing pollutants to and from the air through their leaves. Several studies have found that the aerodynamic effect is greater than pollutant emitted or removal by deposition [2]. In some studies, the inclusion of vegetation has been shown to be beneficial by decreasing pollutant concentrations through deposition on trees, leaves and other green infrastructure [3]. However, vegetation can also increase pollutant concentration in street canyons by obstructing wind circulation. In this study we analyse and quantify the positive and/or negative impacts of trees and type of trees in a downtown area of the city of Madrid (Spain) in a real scenario. The experiment takes into account the atmospheric conditions of the environment, the micro-meteorology of the area, the solar radiation and flow energy balance, traffic emissions, chemical reactions, deposition of pollutants and the dispersion of pollutants in a 3D obstacle (buildings and trees) environment.

Some research indicated the advantages of coupling a micro-scale transport and dispersion model together with a mesoscale numerical meteorological forecast model; substantial enhancements were noted when wind fields were produced by downscaling the output of a weather model as initial and boundary conditions of the CFD [4]. The growing computing power of high-performance computing and major advances in fluid dynamics have generated new research opportunities in air quality modelling in urban environments. In some works, simulation models of large eddies that resolve turbulence have already been applied to cities to investigate air pollution. In earlier researches, other teams have already successfully applied CFD models to simulate NO₂ variability in cities with high (meters) horizontal resolution. Usually for meteorology, several scenarios are considered, but without coupling a mesoscale model to provide initial and boundary conditions, that allow making the CFD simulation with real meteorological data, as it is made in this work. Most urban simulations with CFDs have considered a two-dimensional idealized street canyon or a simplified urban topology, in this case a real complex urban area is modelled, using real trees, streets and 3D buildings data. This work proposes a novel approach to combine complex mesoscale and microscale air quality models with traffic simulation tools that consider emissions data, regional and urban meteorology and variety of chemical and physical mechanisms to simulate air pollution concentrations at different spatial scales.

The significant increase in computing capacity of computers and high performance systems has allowed the use of computational fluid dynamics (CFD) models. These types of models allow us to obtain a detailed three-dimensional representation of the energy flows, wind and concentrations of a city with high resolution (meters) applying them to urban areas with the complexity of modeling obstacles (buildings). There are mainly two types of CFD models, the RANS that are based on the Navier-Stokes equations averaged by Reynolds with parameterized turbulence and the LES for the simulation of large eddies. RANS assumes that non-convective transport in a turbulent flow is governed by stochastic three-dimensional turbulence possessing a broad-band spectrum with no distinct frequencies and, therefore, models all the eddy length scales without distinction. This method has obvious weaknesses and poses serious uncertainties in flows for which large-scale organized structures dominate. In addition, RANS models often assume gradient transport, which may not be the case for pollutant exchange within street canyons. Large Eddy Simulation (LES), although computationally more expensive, has an advantage over RANS in that it explicitly resolves the majority of the energy carrying eddies and the internally or externally induced periodicity involved, and only the universally small eddies are modelled. LES' ability to reproduce the un-steady and intermittent fluctuations of flow fields and, thus, capture the transient mixing process is what makes it numerically superior to conventional RANS, particularly for studies dealing with complex geometries and pollutant dispersion problems.

Urban air pollution is also influenced by short- and long-range transport of gaseous and particulate pollutants from surrounding areas. This is also an important factor to take into account in modelling the air quality of a city, so tools to simulate the transport of pollutants out of cities will have to be included, as is done in this work, including a mesoscale model to provide boundary conditions for the microscale simulation. The dispersion of urban pollutants in the built environment is inherently a multi-scale problem, from the global to the urban scale. We propose to combine the advantages of three-dimensional Eulerian models, which can simulate urban background concentrations of the main air pollutants of interest, and the three-dimensional urban model, which can simulate air pollutant concentrations in complex urban canopy configurations. If we apply a pollution dispersion model over an urban area, we must take into account what happens in and on the urban canopy to determine the spatial-temporal

variation of the simulated air pollutants. The complexity from a computational point of view is how to solve the equations describing the behaviour of the flows, which in these areas are turbulent and therefore unstable and heterogeneous. In this context, computational fluid dynamics (CFD) models are powerful modelling tools to reproduce the dispersion of pollutants taking into account the realistic characteristics of urban environments. Microscale models, such as CFD models, can be used to solve the turbulent flow equations at a higher spatial resolution (on the order of metres) to reproduce in detail the atmospheric processes in the urban canopy layer. These numerical tools assist urban planners and other decision-makers by providing them with detailed knowledge on the possible air pollution mitigation strategies to be implemented in order to be able to assess in advance the different actions within this objective [5].

EXPERIMENT

Three scenarios have been simulated with the CFD PALM4U, a first reference simulation including all the information (broadleaf trees, 3D buildings, emissions, etc...) is called BAU (Business As Usual) scenario. A second scenario where we have removed the trees in the Retiro Park area and is called NOTREE simulation (without trees). The differences in the results of both simulations (BAU-NOTREE) will provide us information about the effect of the trees on the atmospheric composition of the area and thus advance in the research between the interaction between trees and the atmosphere in urban environments. Finally, in the third scenario called ND, we have completed a theoretical exercise to understand the impact on pollution in the area if the trees were all needle-leaf (ND scenario) instead of broad-leaf (BAU scenario) the differences BAU - ND will allow us to know the impact of the type of tree on the pollution. The tree scenarios simulated by means of CFD modeling induces not only deposition changes, but also a thermal and fluxes effects. This experiment will demonstrate the high sensitivity of the modeling tool, as it will be seen how a simple change in the type of trees has implications on the micro-meteorology and of course on the concentration of the pollutants.

To run the CFD domain a multi-scale simulation has been designed to produce boundary conditions to the CFD simulation. First a regional and urban simulation has been run with the WRF/Chem model covering the city of Madrid. The WRF/Chem modeling domains use a Lambert Conformal Projection centered at 40.478°N, 3.704°W with true latitudes of 30°N and 60°N. Three nested grids with horizontal spatial resolution of 25 km (D1), 5 km (D2) and 1 km (D3) centered over Madrid were used for mesoscale simulation. All horizontal domains have 45 (width) by 50 (height) grid cells. The coarse domain covers Iberian Peninsula (D1), the second domain includes the Madrid Community (D2) and the third domain focus on urban Madrid City (D3). Vertically, 33 layers have been used until a height corresponding to a pressure of 50 hPa. The thickness of the layers close to the surface are thinner than those at higher elevations. With this domain configuration, we take into account both the large-scale transport of pollution at national and regional level, as well as the dispersion of pollution at urban scale. The results of the 1 km WRF/Chem simulation are used as initial and boundary conditions for CFD simulation. Turbulence development is accelerated / triggered by using a synthetic turbulence generator, which is applied at the lateral boundaries; and imposes turbulent fluctuations onto the boundary data of the velocity components with characteristic amplitude depending on atmospheric stability inferred from the mean boundary data.

The study urban area for this work is located in Madrid (Spain). The simulations are performed for the period June, 12th to June, 18th, 2017, when high levels of ozone were observed. Fig. 1. shows the 1 km × 1 km area of interest for the CFD simulations. Roads, buildings and trees data were integrated to build a 3D CFD grid. In the area, there are two main roads with very high traffic flows and many street canyons. The area experiences high pollution NO_x episodes. One air quality monitoring station is located in the domain (red star of the Figure 1). This station, called E. Aguirre is classified as traffic station. Part of one big park (Retiro Park) with a lot of trees is present in the west-south of the domain. The total area covered by trees represents 9.9% of the modelled area and the total area covered by buildings represents 43.9% of the modelled area, also the 1.4% of the area are water surface. The horizontal and vertical resolution of the 3D CFD grid is 5 m equally spaced. In height, 60 levels have been used, allowing us to reach a height of 300 m. This covers all the heights of the buildings in the area. In the area of the Retiro Park there are 1194 trees according to the inventory of the Madrid City Council. The predominant species is *Aesculus hippocastanum* known as European horse-chestnut. It is a species of tree of the type, broad-leaf.

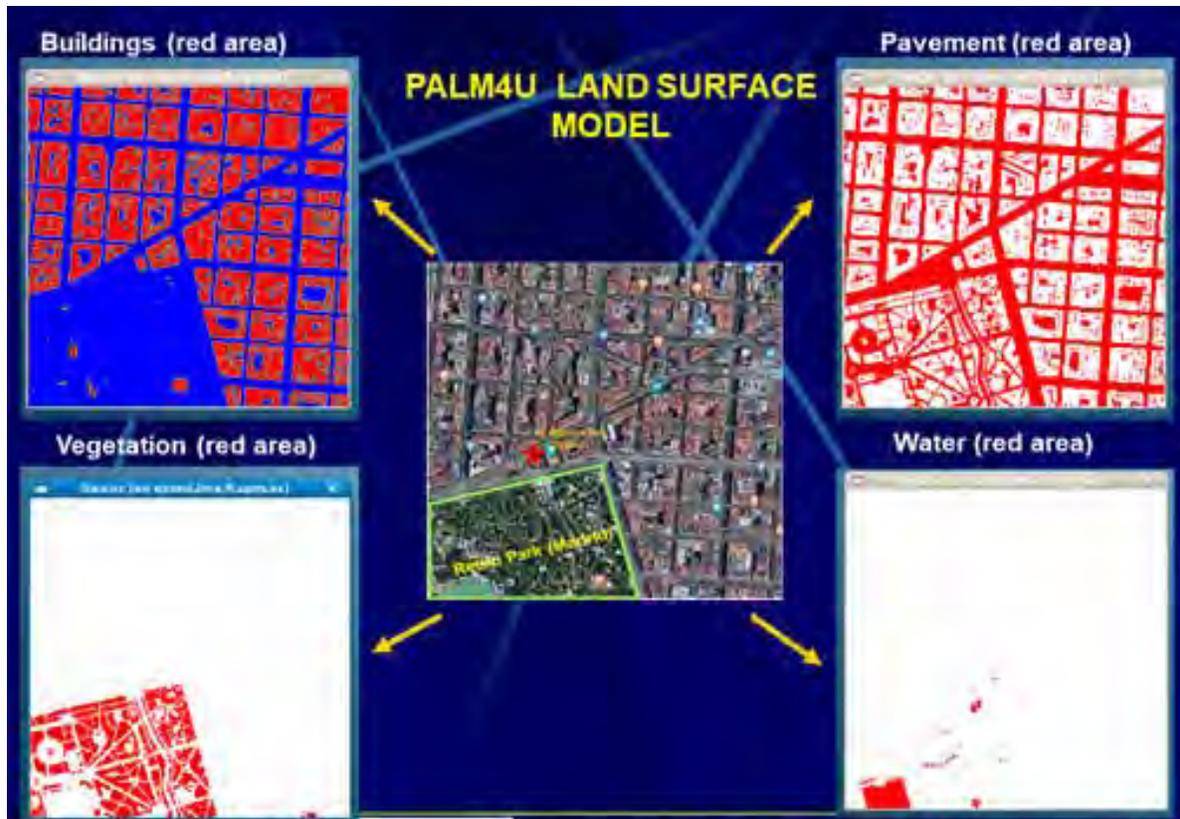


Figure 1. Simulation area (1 km by 1 km) around the E. Aguirre monitoring station (red star) in Madrid (Spain) with the four land surfaces: buildings, pavement, vegetation which includes a green area of the Retiro park and water.

MODELLING TOOLS

The mesoscale modelling tool is the Weather Research and Forecasting and Chem model (WRF/Chem) [6]. The model simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The main advantage of this model is that chemistry and meteorology are solved simultaneously thanks to their coupling, therefore both processes use the same advection, convection and diffusion scheme, on a common grid and without the need for interpolations. This model is widely used by the scientific community and has been evaluated in many experiments [7]. The WRF/Chem model was configured as in phase 2 of the International Air Quality Model Assessment Initiative (AQMEII) [8]. The Carbon Bond Mechanism version Z (CMBZ) is the atmospheric chemical mechanism [9] used for gas phase chemistry. Aerosol chemistry is represented by the Model for Simulating Interactions and Aerosol Chemistry (MOSAIC) [10]. Dry aerosol deposition is simulated following the approach of Binkowski and Shankar [11] and the wet deposition approach follows Easter [12]. Photolysis rates are obtained from the photolysis scheme in Fast-J [13]. We include aerosol-radiant feedback in our simulation. The Rapid Radiative Transfer Model (RRTM) scheme [14] is used to represent both short-wave and long-wave radiation. The Lin cloud microphysics scheme [15] is setup and Grell 3D ensemble cumulus parameterization scheme [16] is used.

The CFD simulation presented in this work were ran using the Parallelized Large-Eddy Simulation Model (PALM) adapted to urban areas (PALM4U) for atmospheric flows [17]. PALM4U solves the three dimensional fields of wind and scalar variables (e.g., potential temperature and scalar concentrations). The performance of PALM over an urban-like surface has been validated against wind tunnel simulations, previous LES studies and field measurements [18]. Buildings are represented as solid obstacles that react to the flow dynamics via form drag and friction forces. Natural and paved surfaces in urban environments are simulated using a multi-layer soil model. It is well-known that vegetation canopy effects on the surface-atmosphere exchange of momentum, energy and mass can be rather complex and can significantly modify the structure of the ABL, particularly in its lower part [19]. It is thus not possible to describe such processes by means of the roughness length and surface fluxes of

sensible and latent heat. To describe the complete 3D structure of individual trees, the plan canopy model uses canopy leave area density (LAD) and basal area density (BAD) as inputs. The plant canopy model is integrated within the detailed radiation model (which includes shadows). The direct, diffuse, and reflected short wave and long wave radiation is partially absorbed by individual grid boxes of plan canopy and transformed to sensible heat flux inside the vegetation. This heat flux is consequently transformed to increase of the corresponding air mass. The plant canopy also emits the long wave radiation according to its current local temperature. An important part of the heat balance in the urban canopy represent the latent heat fluxes from the vegetation. A fully “online” coupled chemistry module is integrated into PALM. The chemical species are treated as Eulerian concentration fields that may react with each other, and possibly generate new compounds, in this experiment the chemistry mechanism CBM4 Carbon Bond Mechanism [20] with 32 compounds and 81 reactions was used. Gases are deposited using the DEPAC module [21].

For the results of the pollutant dispersion model to be useful and of a certain quality it is essential to generate high quality data of the emissions to be injected into the atmosphere and for this we will need to have a detailed description of the traffic flows in the area as they are one of the main sources of emissions in the cities. To meet this requirement in this study we have used a traffic microsimulation model to which we have coupled an emissions model that are detailed below. The traffic intensities and velocity of the vehicles were obtained using a traffic microsimulation SUMO [22]. SUMO (Simulation of Urban Mobility) is an open source tool, space-continuous and time-discrete (1s.) traffic flow simulation platform. Each vehicle is given explicitly, defined at least by a unique identifier, the departure time, and the vehicle’s route through the network (microscopic traffic flow model). The speed of a vehicle is defined in relation to the vehicle ahead. SUMO allows you to use traffic detector data to generate traffic demand. Madrid road network is imported from OpenStreetMap (OSM) and it contains characteristics about streets (number of lanes, address, rounds...) and traffic lights, these data are enough to run SUMO model but the results can be no realistic, so you need to tune the data. The Madrid road network consists of more than 100,000 streets and road segments. Using an iterative process, we have attempted to assure that any intersection would not represent an unrealistic bottleneck for traffic flows. This iterative process was necessary to generate a road network needed by SUMO to provide realistic vehicle flow data for all streets in Madrid. First, random traffic is generated for the Madrid network and then the road detectors have been used as calibrators, which have been used to adapt traffic demand to a certain set of strategies. Traffic conditions are extracted from the more than 3000 road detectors located in Madrid’s streets and highways and 2/3 of them have been used to calibrate traffic simulations. One of the major challenges of traffic simulation has been to ensure a configuration that does not produce unrealistic traffic blocks and congestion. The calibration process is an iterative process where the configuration parameters of the model are changed until the measured traffic flow values do not cause congestion in the traffic network. In each simulation through visual observation and counting of vehicles on street segments, the blockage areas are identified and parameters of the streets involved are modified. An appropriate emissions model is essential to transform the instantaneous data into estimations of NO_x for use within PALM4U. Traffic emissions are calculated using the detailed methodology (Tier 3) as described in the EMEP/EEA Air Pollution Emission Inventory Guidebook (EMEP/EEA, 2016). For each category, specific emission factors are defined, which are dependent on the speed of the vehicles. The emission factors are split into vehicle categories (passenger cars, light commercial trucks, heavy duty vehicles including buses and motorcycles). Vehicles are classified into different categories according to fuel type, vehicle weight, and vehicle age and engine capacity. For each category, specific emission factors are defined, which are dependent on the speed of the vehicles. The composition of the vehicles fleet was collected from vehicle registration data sets in Madrid for December 2016. In addition to the vehicle and fuel type, classification also takes into account the vehicle’s engine type, vehicle technology (age of vehicles).

RESULTS

Modelled results are initially compared with daily observational data from the E. Aguirre monitoring station to evaluate the BAU simulation for O₃ and NO₂ pollutants. The model performance was analysed based on time series (Fig. 2.) and statistical analysis was performed to help to determine the accuracy of the modelling results. The following statistical parameters have been calculated: Normalized Mean Bias (NMB); Root Mean Square Error (RMSE) and Pearson’s temporal correlation (R²). The R² was found to be 0.6 for NO₂ and 0.7 for O₃, The NMB values are -6% for NO₂ and -19% for O₃, the negative values of NMB indicated an underestimation of the simulated concentration against the observational data. The resulting RMSE is below 30 µg/m³ for both pollutants. We can conclude that the BAU simulation for the NO₂ and O₃ dispersion with respect to the measured values in a specific point of the domain (5 m x 5 m where the monitoring station is located) is appropriate. It is important to highlight that the performance results of the CFD simulation are similar to the performance of the WRF/Chem simulation at 1 km spatial resolution as the surrounding concentrations have a strong influence on the local area concentrations.

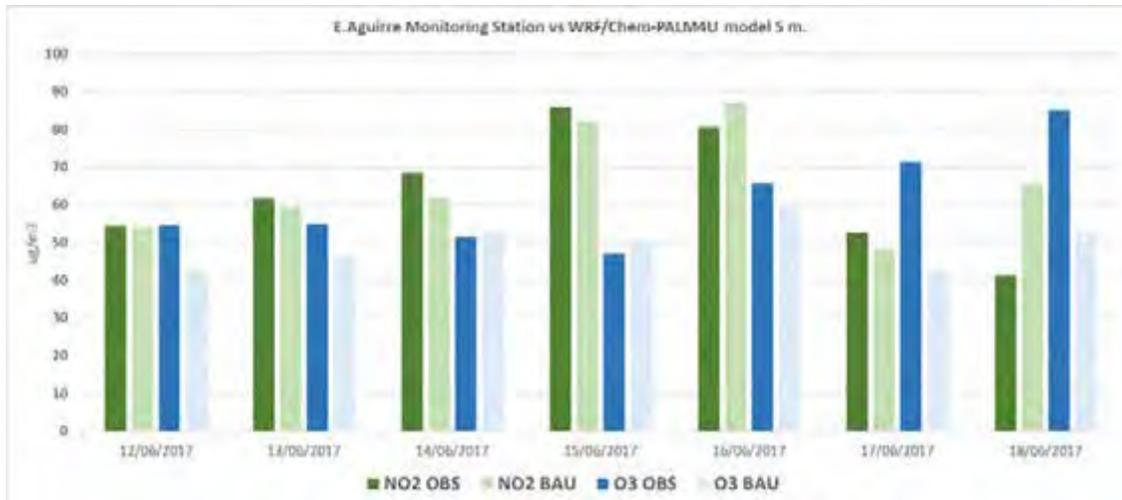


Figure 2. Time series of daily observed and modelled NO_2 (top) and O_3 (bottom) concentrations.

Once validated the BAU simulation, the BAU, NOTREE and ND simulations are used to evaluate the effects of trees and type of trees on concentration levels of O_3 and NO_2 concentrations (Fig. 3.). Fig. 3 shows the changes in NO_2 and O_3 concentrations (%) if the trees were removed from the green area (down-left). In the figure we can see that in the streets around the green zone, the trees are increasing the NO_2 concentrations up to 20%, these increases were also seen in other narrow streets further away from the green zone. The increases in NO_2 next to the park due to the presence of trees cause large decreases in O_3 concentrations of up to 40%. In general, the presence of trees decreases the temperature of the area and reduces the O_3 concentrations, the trees decrease the concentration in 86.62% of the grid cells, with an average reduction of 4.84%, but increase the NO_2 concentrations in 70.97% of the cells, with average increases of 4.76% as the presence of the trees hinders the ventilation in the area close to the green area.

Fig. 4. shows the spatial distribution of changes (BAU-ND %) in O_3 and NO_2 concentrations when changing from broad-leaf trees in the green zone to needle-leaf trees. The trees change the distribution of O_3 and NO_2 concentrations, particularly on some hotspots. The effects of type of trees (Figure 5) is quite heterogeneous leading to decreases or increases of O_3 and NO_2 concentrations at pedestrian height.

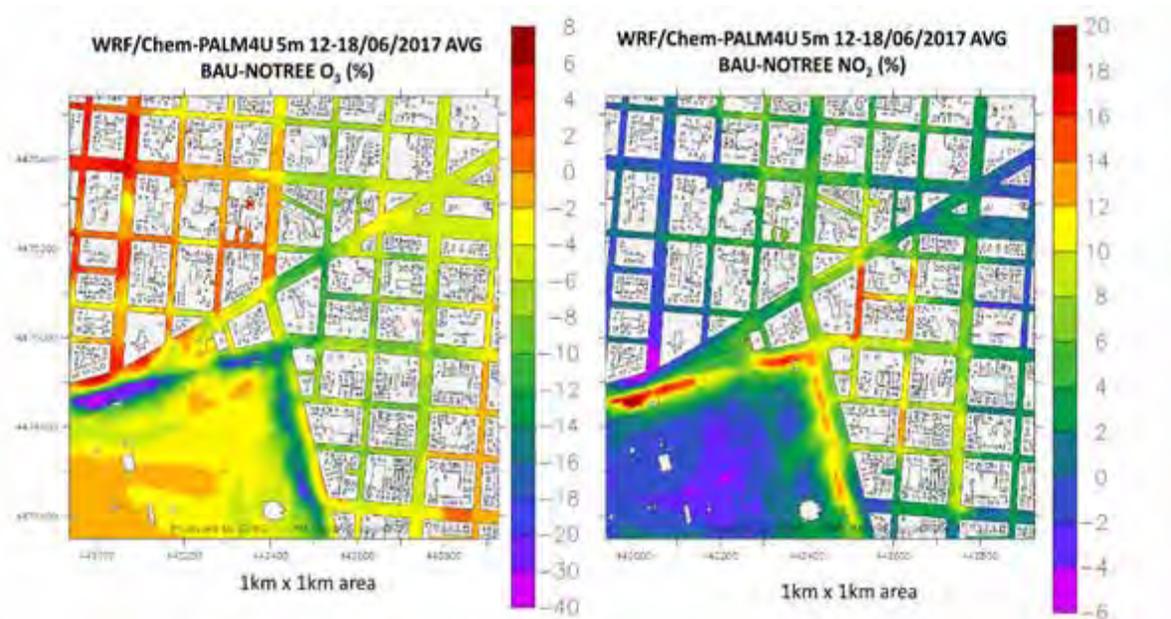


Figure 3. Spatial distribution with 5 m. spatial resolution of the effects of trees (BAU-NOTREE %) on O_3 and NO_2 hourly averaged concentrations for the period 12-18/06/2017.

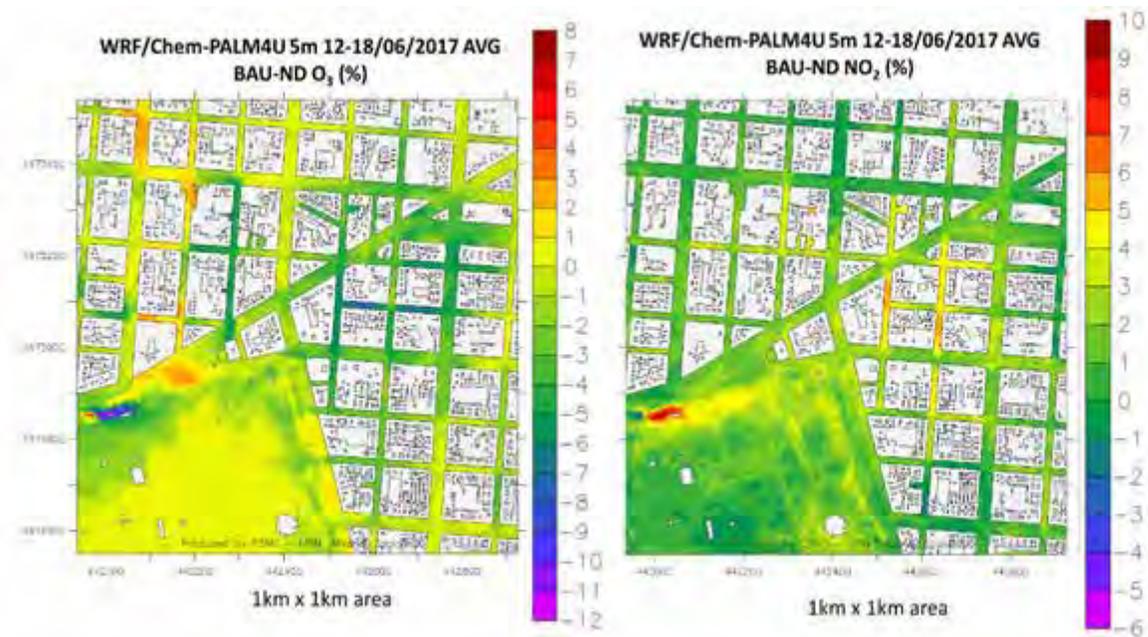


Figure 4. Spatial distribution with 5 m. spatial resolution of the effects of type of trees (BAU-ND %) on O₃ and NO₂ hourly averaged concentrations for the period 12-18/06/2017.

Changing the tree type from broad-leaf to needle-leaf involves changing the minimum canopy resistance parameter (R_{c_min}) in Eq. 1. For broad-leaf trees (BAU), R_{c_min} has a value of 240 s/m and for needle-leaf trees (ND) the value changes to 500 s/m. This is the main parameter that changes from one simulation to another. Then in the ND simulation in the cells with trees the canopy resistance (R_c) is higher and therefore the latent heat flux (LE) is lower when calculated with Eq. 2 which causes an increase in temperature. This temperature increase causes O₃ concentrations to increase in 64.22% of the cells with an average increase of 1.93% and NO₂ concentrations to decrease in 90.67% of the grid cells with an average decrease of 1.69%.

$$R_c = \frac{R_{c_min}}{LAI} f1(R) f2(Hm) f3(e) \quad (\text{Eq. 1})$$

$$L = -\rho l_v \frac{1}{ra + rc} (q_v - q_{v,sat}) \quad (\text{Eq. 2})$$

R_c : Canopy resistance

LAI: Leaf are index

f2: Corrector factor based on soil humidity

L: Latent heat flux

l_v : Latent heat of vaporization

rc : Canopy resistance for vegetation

$q_{v,sat}$: Water vapor mixing ratio at temperature T0.

R_{c_min} : Minimum canopy resistance

f1: Corrector factor based on solar radiation

f3: Corrector factor based on water-vapor pressure deficit

ρ : Air density

ra : Aerodynamic resistance

q_v : Water vapor mixing ratio

CONCLUSIONS

An integrated urban air quality modelling system has been implemented. The tool includes an emission model (EMIMO), a traffic model SUMO, a pollutant transport and chemistry model (WRF/Chem) and the CFD PALM4U model (LES mode) with chemistry. The PALM4U 5 m simulation reproduces pollutant dispersion in the presence of boundary and top conditions supplied by the WRF/Chem 1km simulation, real building morphology, vegetation and hourly emissions. The results obtained allow us to confirm that the modeling tool (WRF/Chem-PALM4U) presented is capable to reproduce successfully the distribution of the concentration of pollutants over urban areas. An experiment has been run to analyze the effects of trees and type of trees on air pollution. Three simulations were run, with broad-leaf trees (BAU), without trees (NOTREE) and with needle-leaf trees (ND) (changing the type of tree over a green area) in a 1 km x 1 km area.

Results show that the effects of urban vegetation on local air quality can be very complex and have a substantial impact in local and potentially large urban areas. The trees can either decrease or increase NO₂ and O₃ concentrations over the 1 km x 1 km domain with different impacts each day. On streets close to the green area we found that trees can increase NO₂ concentrations by up to 20% and reduce O₃ concentrations by 30%. However, on the green area, trees can reduce NO₂ concentrations by 5% with modest increments of O₃ of up to 2%. We found that needle-leaf trees can decrease NO₂ concentrations and increase O₃ concentrations. Trees in general and Needle-leaf trees reduce latent heat flux (Rc bigger than broad-leaf trees) and increase sensible, ground heat flux and temperature, favoring O₃ formation. The results are agreeing with other studies where deposition velocities were higher on needles than on broadleaves [23] and that trees considerably affected the accumulation of transported pollutants [24].

The modelling tool applied over a real 3D urban topography can provide a large amount of detailed information with high-resolution about the flow concentration fields and heat fluxes. This work demonstrates how these type of numerical simulation tools can generate information about potential mitigation actions on a scale of meters and obtaining information on their effectiveness.

ACKNOWLEDGMENTS

The UPM authors thankfully acknowledge the computer resources, technical expertise and assistance provided by the Centro de Supercomputación y Visualización de Madrid (CESVIMA). The UPM authors thankfully acknowledge the computer resources, technical expertise and assistance provided by the Red Española de Supercomputación..

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THE OUTLOOK OF THE GREENER CITIES PARTNERSHIP (GCP)

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ABSTRACT

The United Nations Environment Programme and the United Nations Human Settlement Programme have developed the Greener Cities Partnership (GCP) as a joint international environmental initiative based on sustainable development, green concept, and smart green city approaches. This collaboration integrates ecological considerations and urban policy-making through dialogue and engagement of various stakeholders on global, national, and local priorities. Resilient and resource-efficient cities, sustainable transport and mobility, and waste and wastewater management are three pillars of this partnership. Moreover, focusing on a broader green vision for cities, including environmental, economic, social, ethical, and political factors, causes the GCP's connection with the City Prosperity Initiative (CPI). The GCP has launched some international pilot programmes to monitor Sustainable Development Goals (SDGs), including the city of Qazvin in Iran. It aims to enable the municipality to create baseline data on the city prosperity related to urban sustainable development goals indicators and monitor specific urban environmental measures with the Greener Cities Partnership. The GCP develops a list of recommended indicators for adding to the extended CPI framework to enhance the city's quality and in-depth monitoring. The new indicators tackle water quality, water usage efficiency, reducing potable water use for non-drinking purposes, wastewater management, public transport, and preservation of natural heritage.

KEYWORDS

Greener Cities Partnership (GCP), Sustainability, Green Vision, Smart Green City, Sustainable Development Goals (SDGs), City Prosperity Initiative (CPI)

INTRODUCTION

In the era of the ecological attitude, one of the most critical issues in the world is human population growth, especially in urban areas. The ecosystem and natural environment face tremendous urban population growth and restrictions on development [15]. Today, 55 percent of the world's population lives in the cities. It is expected that by 2050, 70 percent of humanity will be urban. Meanwhile, growth in urban population is predominantly taking place in the cities of developing countries. Unplanned and poorly managed urbanization affects people and the environment negatively. About 1 billion slum dwellers currently suffer from economic, social, and physical exclusion and segregation. Piecemeal and speculative development is mainly responsible for the fragmentation, degradation, and destruction of natural habitat and undermining fertile agricultural areas and ecosystem services. Due to heavy development pressure, many cities lock themselves into unsustainable land-use patterns undergoing rapid changes. They are responsible for a large share of inappropriate resource consumption and environmental impacts. They are significant generators of waste and greenhouse gas (GHC) emissions. Thus, increasingly, urban areas are exposed to geological and climate change-induced risks [10], [11], [19], [20], [27], [30].

Figure 1 presents urban/rural populations as a proportion of the total population by the geographic region from 1950 to 2050. Today, at or above 80 percent, high levels of urbanization characterize Latin America, the Caribbean, and Northern America. Africa and Asia, in contrast, remain primarily rural, with 43 percent and 50 percent of their respective populations living in urban areas. Europe and Oceania have respectively 75 and 68 percent as urban population. Over the coming decades, urbanization is expected to increase in all regions, more rapidly in Africa and Asia. Figure 2 shows this global urban population growth propelled by cities of all sizes in 1990-2030.

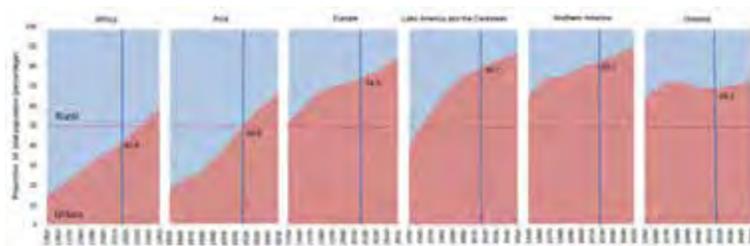


Figure 1. Urban/rural population as a proportion of the total population (1950–2050) [25]

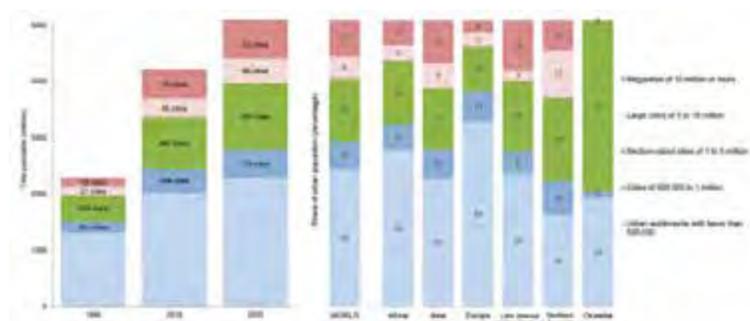


Figure 2. Urban population growth, propelled by size class of urban settlement (1990, 2018, and 2030) [25]

These vital issues and challenges of the urban development process regarding environmental and ecological sustainability cause a sense of necessity to consider new directions and solutions. As a guiding principle, the Green City concept has been transformed to a goal from a perspective within the last recent decades [3], [4]. It indicates a narrower vision of a city with wide green spaces and the broader perspective referring to environmentally sustainable performance [19]. Accordingly, as a global environmental agenda, the UNEP and the UN-Habitat have integrated their professional networks and technical capacity to a Greener Cities Partnership (GCP). It is envisioned that this collaboration will improve synergy between the two agencies and their partners. Therefore, this paper has focused on the outlook of the Greener Cities Partnership (GCP) as a new direction regarding sustainable urban development. For this purpose, three main parts have been considered as follows:

- Green city definitions in terms of concepts, characteristics, and approaches;
- Greener Cities Partnership (GCP) including background, objectives, and priorities;
- Monitoring Sustainable Development Goals (SDGs) associated with the City Prosperity Initiative (CPI) in Qazvin as an international pilot programme;

GREEN CITY DEFINITIONS

The green or sustainable development approach among the overall spectrum of human living has resulted in the green city concept [16]. The green city concept as a composite perspective includes the core connotations of managing urban growth under ecological limitations, shaping green landscape style, and protecting historical and cultural heritage [40]. The first clear green concept appeared in the 1970s when relationships were noticed between economic growth, social development, environment, and natural resources. Accordingly, sustainable development was defined as “the right to meet the development aspirations of the present generation without limiting the rights of future generations.” The mechanism of this global concept comes down to achieving three main objectives as follows [9]:

1. Ecological - meaning preventing degradation of the environment and eliminating their risks;
2. Economic - expressing itself in satisfying basic material needs of humanity by using techniques and technology that does not destroy the environment;
3. Social - that is to secure the social minimum or standard, healthcare, development of the spiritual sphere, safety, and education;

The so-called green herein as green development versus non-green development means harmless to the environment and advantageous to the natural resources concerning not destroying the environment and ecological equilibrium. Accordingly, the green city can be interpreted as green building and architecture regarding “reducing environmental load, fully using sunshine, saving energy, and bringing residents with the feeling close to nature and making harmonious and sustainable development” [7], [37]. Environmental sustainability is characterized as “the maintenance of natural capital, with natural capital as a provider of inputs (e.g., air, water, energy) and as a sink of waste emissions (e.g., greenhouse gases).” In this definition, green cities are sustainable in terms of ecological impact, clean in terms of air and water, resilient in terms of natural disasters, and finally healthy in terms of major infectious disease outbreaks. These characteristics subsequently encourage green behavior [17].

“A green city is a city designed with the consideration of an environmental place inhabited by people, who are dedicated to the minimization of waste output and pollution, amongst other things” [14]. There are many sustainability approaches, including green city, eco-city, and livable city. Each approach focuses on specific issues of sustainability. So, green cities are cities striving to lessen their environmental impacts by reducing waste, expanding recycling, lowering emissions, increasing housing density while expanding open space, and encouraging the development of sustainable local businesses [5].

European Commission (EC) defines the green city by green infrastructures such as parks, urban gardens, and surrounding greenness that can reduce the impacts of increased heat exposure due to human activities and heat-amplifying effects of the built environment, contemporary car-centric city designs, sedentary lifestyle, and high levels of air pollution and noise. Moreover, green infrastructure provides well-known benefits for physical and mental health, promotes active and public transport, prepares adequate space to encourage exercise, and mitigates the impacts of environmental hazards in cities [6]. Other interpretations in terms of green housing by green materials or green construction methods and green space including green axes, greenways, green paths, and the most recent ones such as green roof or eco-roof, green wall, and green facade as sustainable elements of the built environment can be considered as the green infrastructure with the goals of protection of land and natural environments and promotion of quality of life inside the cities [21], [22], [24], [39].

Wang et al. argue that “the idea of the green city is based on the harmonious development of man and nature, pursues harmonious and sustainable development of economy, resources, and environment, and finally achieves a perfect living area with convenient transportation, efficient use of natural energy, and good living environment.” Greening cities could produce a set of broader economic and social benefits such as decreasing carbon emissions, improving production efficiency, encouraging innovation, and reducing the capital and operating cost of infrastructure. A green urban economy based on green building and energy efficiency is part of the comprehensive transition of cities and metropolitan areas towards sustainable development through green city strategy [36].

Accordingly, today, all cities tend to define themselves as green cities or greener cities, transitioning towards being green cities or aspiring to be green cities. Green spaces, parks, and natural landscapes, the quality of the city’s transport system, energy systems, and water and waste management systems are among the most prominent green characteristics and assets. However, green objectives for cities seem to be more driven by social and political changes than environmental ones, resulting in essential triggers for adopting green objectives as public opinion and awareness, changes in local political leadership, and pressure from stakeholders [18].

On the other hand, the green city trend complements the smart city. The smart green city paints a picture of a multifunctional place of dwelling, work, recreation, and transport with a systematic infrastructure through intelligent, integrative, and effective energy monitoring [12]. In the case of development processes, increasing urban functionality needs design ideas, the right social background, and sources of financing any essential investments. Thus, smart, eco-friendly cities are characterized by the following features to alleviate negative externalities [13], [23]:

- application of renewable energy;
- electric or low emission mobility;
- smart management of power consumption;
- smart management of supplies;
- management of recycling and waste;
- rational use of available space;
- public safety and intelligent monitoring;

GREENER CITIES PARTNERSHIP (GCP)

To advocate and promote environmental sustainability in urban development and to mainstream environmental considerations into urban policy-making, the United Nations Environment Programme (UNEP) and the United Nations Human Settlement Programme (UN-Habitat) have jointly developed the Greener Cities Partnership (GCP). This partnership can provide city-level focus, including urban and regional follow-up and review based on the global and national level analyses towards the sustainability concerning the Sustainable Development Goals. The Sustainable Development Goals, officially known as Transforming our world: the 2030 Agenda for Sustainable Development, are 17 SDGs with 169 associated targets adopted by world leaders in September 2015. Goal 11, sustainable cities and communities, could be a central focus to include and encompass the other goals and areas. Moreover, after the Third United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in October 2016, the role of the partnership in implementing the urban environmental targets of the Sustainable Development Goals is more crucial than ever. The New Urban Agenda, which sets a new global standard for environmentally sustainable and resilient urban development and will help rethink how we plan, manage and live in the cities, is the primary framework document concerning that purpose.

Therefore, the objective of the Greener Cities Partnership is to mainstream environmental perspectives into various spatial scales and all levels of governance such as local, national, and global urban policy-making and highlight local-global linkages of ecological issues. Accordingly, Greener Cities Partnership is an incubator of ideas for collaboration and innovation while serving local, national, and international stakeholders in various activities. The Greener Cities Partnership is open to innovation and enables successful collaboration between the two mentioned UN programmes. Past partnership priorities have included ecosystem-based adaptation to climate change, green building, and transport planning. The development of new joint activities is a process of stakeholder engagement, dialogue, and reflection of global, national, and local contexts [31]. Current priorities of this joint UNEP and UN-Habitat Initiative include three principal dimensions as follows [27], [30]:

1. Resilient and Resource-Efficient Cities

- Provide a better understanding of how resource efficiency impacts the resilience of cities;
- Build political support for establishing an innovative initiative for resilient and resource-efficient cities with the participation of a broad range of stakeholders;
- Global focus with crucial topics including city-level ecosystem-based adaptation, integrated resource flows, urban sprawl, and planned city extensions;

2. Sustainable Transport and Mobility

- Support bus rapid transport and non-motorized transport facilities;
- Contribute to the transport component of the low-carbon development;
- Establish a forum for promoting sustainable transport and support the development of an action plan for sustainable transportation;

3. Waste and Waste Water Management

- Make integrated waste management strategies that include both solid waste and wastewater management;
- Launch integrated comprehensive waste management strategies including capacity building activities;
- Coordinate and establish a system to disseminate the knowledge produced from the strategy development and piloting;

The activities depend on the feasibility of cooperation, as long as they emphasize areas that help shape greener cities and sustainable urban developments.

MONITORING SUSTAINABLE DEVELOPMENT GOALS (SDGs) IN QAZVIN

Greener Cities Partnership (GCP) recently has launched an international pilot programme in Qazvin in Iran to monitor Sustainable Development Goals (SDGs). The purpose is to enable the municipality to make baseline data on the city prosperity related to urban sustainable development goals indicators and monitor specific urban environmental measures with the support of the Greener Cities Partnership. Qazvin is the first case to use the City Prosperity Initiative (CPI) as a platform for monitoring urban environmental SDGs involving UNEP and UN-Habitat. Thus, it is possible to link the GCP and CPI together [31], [32].

Prosperity is the leading terminology in this regard. The 2030 Agenda, as a plan of action for people, planet, and prosperity, defines prosperity as “we are determined to ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social and technological progress occurs in harmony with nature” [34]. Moreover, in the New Urban Agenda, it has been emphasized that “We share a vision of cities for all, referring to the equal use and enjoyment of cities and human settlements, seeking to promote inclusivity and ensure that all inhabitants, of present and future generations, without discrimination of any kind, are able to inhabit and produce just, safe, healthy, accessible, affordable, resilient and sustainable cities and human settlements to foster prosperity and quality of life for all” [35].

As a new paradigm, sustainable development presents a significant milestone and sets out a new development agenda and framework for humanity’s socio-economic and environmental sustainability [1]. Therefore, the City Prosperity Initiative as a multidimensional index argues for the need to move towards the broad conception of human and societal well-being regarding sustainability. Hence, the prosperity of a city is determined based on a collection of factors or dimensions composed of sub-dimensions and indicators. Productivity in terms of the economic growth and development for the entire population, Infrastructure Development as the physical assets, amenities and technologies, Quality of Life in terms of the living standards associated with the safety and security, education, health, and recreation, Equity and Social Inclusion as the poverty and inequalities eradication and equitable distribution of the wealth and benefits, Environmental Sustainability in terms of protection and preservation of the urban environment and natural assets, and finally Urban Governance and Legislation as the adequate and transformational institutional arrangements are six dimensions of the CPI Index [2], [28], [38].

On this base, an equitable prosperous sustainable city has been focused as a productive city, a resilient city, a safe and healthy city, an inclusive city, a green city, and a planned city [26]. Each dimension comprises sub-dimensions, defined from a group of variables or indicators measured for each city. When sub-dimensions are made-up by two or more indicators, they are aggregated into a single value. Indicators are standardized using the internationally-observed benchmark. A clear definition of each indicator is presented in the Measurement of City Prosperity: Methodology and Metadata [29]. Figure 3 and Table 1 show the dimensions, sub-dimensions, and indicators of the City Prosperity Initiative Index. Accordingly, this multidimensional index has 22 sub-dimensions and 62 indicators conceptualizing a prosperous city.



Figure 3. Dimensions and main sub-dimensions of the City Prosperity Initiative Index [28]

Table 1. Dimensions, sub-dimensions, and indicators of the City Prosperity Initiative Index [29]

| DIMENSION | SUB-DIMENSION | INDICATOR | DIMENSION | SUB-DIMENSION | INDICATOR |
|---|-----------------------------------|---|---|-----------------------------------|--|
| PRODUCTIVITY (P) | 1. Economic Strength (ES) | 1.1 City Product per capita | QUALITY OF LIFE (QOL) | 2. Education (E) | 2.1 Literacy Rate |
| | | 1.2 Old Age Dependency Ratio | | | 2.2 Mean years of schooling |
| | | 1.3 Mean Household Income | | | 2.3 Early Childhood Education |
| | 2.1 Economic Density | 2.4 Net enrollment rate in higher education | | | |
| | 2. Economic Agglomeration (EA) | 2.2 Economic Specialization | | 3.1 Safety and Security (SS) | 3.1 Homicide rate |
| | | 2.1 Unemployment Rate | | | 3.2 Theft rate |
| | | 2.2 Employment to Population Ratio | | | 4.1 Accessibility to Open Public Areas |
| | 2.3 Informal Employment | 4.2 Green Area per Capita | | | |
| | 3. Employment (E) | 3.1 Unemployment Rate | | EQUITY AND SOCIAL INCLUSION (ESI) | 1. Economic Equity (EE) |
| 3.2 Employment to Population Ratio | | 1.2 Poverty Rate | | | |
| 3.3 Informal Employment | | 2.1 Slums Households | | | |
| 1. Housing Infrastructure (HI) | 1.1 Improved Shelter | 2. Social Inclusion (SI) | 2.1 Youth Unemployment | | |
| | 1.2 Access to Improved Water | | 3.1 Equitable Secondary School Enrollment | | |
| | 1.3 Access to Improved Sanitation | | 3.2 Women in Local Government | | |
| | 1.4 Access to Electricity | | 3.3 Women in Local Work Force | | |
| | 1.5 Sufficient Living Area | 3. Gender Inclusion (GI) | 4.1 Land Use Mix | | |
| | 1.6 Population Density | | 3.1 Number of monitoring stations | | |
| 2. Social Infrastructure (SI) | 2.1 Prisoner Density | 4. Urban Diversity (UD) | 3.2 Air Quality (AQ) | | |
| | 2.2 Number of Public Libraries | | 3.1 Number of monitoring stations | | |
| | 3.1 Internet Access | | 3.2 AQI-5 Concentration | | |
| 2. Information and Communication Technology (ICT) | 3.2 Home Computer Access | ENVIRONMENTAL SUSTAINABILITY (ES) | 3.3 CO2 Emissions | | |
| | 3.3 Average Broadband Speed | | 2.1 Solid Waste Collection | | |
| | 4.1 Use of Public Transport | | 2.2 Waste Water Treatment | | |
| | 4. Urban Mobility (UM) | 4.2 Average Daily Travel Time | 2. Waste Management (WM) | 2.3 Solid Waste Recycling Rate | |
| | | 4.3 Length of Mass Transport Network | | 3.1 Share of Renewable Energy | |
| | | 4.4 Traffic Fatalities | | 3. Subsidy Energy (SE) | 3.1 Voter Turnout |
| 4.5 Affordability of Transport | 3.2 Civic Participation | | | | |
| 5.1 Street Intersection Density | 2.1 Open Revenue Collection | | | | |
| 5. Urban Form (UF) | 5.2 Street Density | 2. Municipal Financing and Institutional Capacity (MFC) | 2.2 Open to Start a Business | | |
| | 5.1 Land Allocated to Streets | | 2.3 Subnational Debt | | |
| | 1.1 Life Expectancy at Birth | | 2.4 Local Expenditure Efficiency | | |
| QUALITY OF LIFE (QOL) | 1. Health (H) | 1.2 Under-Five Mortality Rate | 3. Governance of Urbanization (GU) | 3.1 Land Use Efficiency | |
| | | 1.3 Vaccination Coverage | | | |
| | | 1.4 Maternal Mortality | | | |
| | | | | | |

Qazvin is one of the oldest Iranian cities, rich in culture and history, and geographically diverse. It also has an impressive record of innovative development programmes and has received several environmental certificates and other awards. The city continues to grow and needs to establish a monitoring system linked explicitly to ecological challenges, which helps collect and Analyze long-term data for more sustainable policies and actions. There are many indicators that have direct relevance to the urban environment. The GCP proposes Qazvin work on establishing a set of indicators most relevant to the local challenges that the city faces. They include climate change, air pollution, dust storms, decay of green historical and public sites, public transport, water scarcity, water quality, water usage efficiency, waste and wastewater management, and preservation of natural heritage. The GCP and CPI monitor the indicators for a mutually agreed duration. A policy action plan will be derived from the data and information obtained. It is expected that the action plan improves the prosperity of the city in a multidimensional way, including multiple areas of urban ecology, urban governance, urban planning, basic services, and municipal finance [8], [32], [33].

DISCUSSION AND CONCLUSION

For sustainability realization, integrating ecological, economic, and social priorities is essential. In following this path, it is crucial to pay attention to the opportunities and constraints in different levels and scales of global, national, regional, and local. The green city derived from the green concept and as an approach concerning sustainability indicates three main areas, including reducing (hazards, pollutions, emissions, and wastes), expanding (green spaces, green infrastructures, green energies), and recycling (sources and materials) in terms of sustainable urban development. Thus, this approach is associated with smart city and, accordingly, smart green city implications regarding the cities' production, supply, use, and consumption processes through intelligent, rational, integrative, and effective monitoring and management. Other green objectives such as public awareness, good governance, and public participation are the basic requirements.

As Table 2 shows, Greener Cities Partnership (GCP) is a joint initiative by the UNEP and the UN-Habitat that creates a clear consensual reference framework associated with the green city approach. The primary purpose of the GCP is to integrate the environmental considerations and urban policies that shape the cities as the current and future dominant form of human habitation. Accordingly, city or local level focus within the broader spatial levels of the follow-up and review on regional, national, and global scales has been provided towards sustainability. The 2030 Agenda for sustainable development by UNEP and the New Urban Agenda for sustainable urban development by UN-Habitat can direct and conduct this direction. This cooperation emphasizes a broad range of stakeholders regarding dialogue/engagement on the priorities in different spatial scales. Resiliency and resource efficiency, low-carbon and non-motorized mobility, and integrated solid waste and wastewater management are three main appropriate dimensions considered through the innovative capacity building and ecosystem-based adaptation approaches regarding the cities and urban environments. On this base, the city of Qazvin has been launched as an international pilot for Greener Cities Partnership. Creating baseline data and information related to the urban Sustainable Development Goals (SDGs) indicators that are most relevant to the local challenges and finally, policy action plan derived from them are the critical objectives.

Besides, focusing on a more comprehensive green vision for cities, including environmental, economic, social, ethical, and political factors, causes coupling the Greener Cities Partnership (GCP) with the City Prosperity Initiative (CPI). The City Prosperity Initiative is a comprehensive multidimensional index that consists of six key factors or dimensions associated with the city and urban settlements, including Productivity, Infrastructure Development, Quality of Life, Equity and Social Inclusion, Environmental Sustainability, and Urban Governance and Legislation. Each aspect includes sub-dimensions defined by some measures or variables. Therefore, a broad framework for monitoring and guiding the urban development process concerning sustainability can be established and adapted to the contextual/local conditions, issues, and dynamics. Further studies on this direction can be addressed in future research to achieve and clarify the supplementary theoretical and empirical findings.

Table 2. Incremental consensual reference framework to found the Greener Cities Partnership (GCP)

| | |
|---|---|
| Sustainable Development Paradigm | |
| Environmental concerns and subsequently sustainable development paradigm set out a new development agenda concerning the socio-economic and environmental sustainability of humanity. | |
| Green Concept | |
| The green concept indicates on harmless to the environment, advantageous to the natural resources, and sustainable, clean, resilient, and healthy, respectively, in terms of ecological impact, sources, natural disasters, and diseases. | |
| Green City Approach | |
| Green city as a specific approach along with sustainability aims at harmonious and sustainable urban development through: 1- Reducing (hazards, pollutions, emissions, and wastes); 2- Expanding (green spaces, green infrastructures, green energies); 3- Recycling (sources and materials); 4- Encouraging (innovation and efficiency in production and consumption processes); 5- Other green objectives (public awareness, good governance, and public participation). |  |
| Smart Green City Approach | |
| A smart green city is a multifunctional place with a systematic infrastructure through an intelligent, rational, integrative, and effective use, application, monitoring, and management to alleviate negative externalities. | |
| Greener Cities Partnership (GCP) | |
| 2030 Agenda for Sustainable Development Goals (SDGs) Sustainable Cities and Communities | New Urban Agenda Sustainable and Resilient Urban Development |
| UNEP and UN-Habitat have jointly developed the Greener Cities Partnership (GCP) to advocate and promote environmental sustainability in urban development and mainstream ecological considerations into urban policy-making. This partnership can provide city-level focus, including review and follow-up based on the global, national, and regional level analyses towards sustainability regarding the current priorities: |  |
| 1. Resilient and Resource-Efficient Cities; 2. Sustainable Transport and Mobility; 3. Waste and Waste Water Management; |  |
| International Pilot Programmes for the GCP Associated with the CPI | |
|  | The objective is to monitor urban environmental Sustainable Development Goals (SDGs) with support of the Greener Cities Partnership (GCP) associated with the City Prosperity Initiative (CPI) as a platform. The CPI multidimensional index argues for the need to move towards the broad vision of human and societal well-being in terms of sustainability based on the conceptualizations of urban prosperity through six main dimensions of Productivity, Infrastructure Development, Quality of Life, Equity and Social Inclusion, Environmental Sustainability, and Urban Governance and Legislation. Each dimension comprises some sub-dimensions, defined by a group of variables or indicators. Accordingly, an equitable, prosperous, and sustainable city was considered as productive, resilient, safe and healthy, inclusive, green, and planned. |

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SUSTAINING OF ENVIRONMENTAL IDENTITY IN NORTH EGYPT BY FACING THE CHALLENGES ON BURULLUS LAKE

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ABSTRACT

North Egypt is featured environmentally by four coastal lakes. As Burullus Lake, one of these lakes, has many ecological and cultural values, it has rare and sensitive landscape and seascape elements. Accordingly, it has been characterized by a unique identity socially and environmentally. In the coming future, the lake might be existed from the category of protected areas, if the current deterioration continues with the same trend. Moreover, it might be disappeared, and the environmental identity in North Egypt might be diminished. By addressing the constraints that could decrease the probability of the lake's existence, the research aims to develop a group of sustained actions associated with some recommendations to protect the sensitive environment of the lake. Finding deteriorations from field visits should be considered in management planning for the lake's sustainability to be considered by decision-makers. To restore the health of the lake, it should be taking action to protect the habitats and green economic opportunities. The proposed solutions are empowering actions, which focus on the engagement of civil bodies and social participation. The wetlands protection builds on changing the unsustainable practices, which is an opportunity to mainstream the environmental identity, which aims to inactive the encroachment and pollution in the lake's water and its surrounding wetlands. Finally, the study recommends with a group of considerations, through the investigated study, to be a concern for a wider application on the distinctive environmental features.

KEYWORDS

Environmental identity, Burullus Lake, North Egypt, sustainability

INTRODUCTION

Places and ecosystems interact like humans. Accordingly, each of them has a unique and special identity, even if it had passed with certain anthropological and physical changes that impacted on its daily circumstances, but it will remain on its huge spirit. Not only the culture and social events make a sense of place and our identity, but also the habitats and their ecological diversity make our environmental identity [1], [2], [3]. Without a liveable and healthy environment, the man could not make his living standards (e.g. shelter, food, water). The deterioration could eliminate traces of environmental identity.

Nile Delta has formed across many geological ages by the sedimentation process of Nile River branches. These riverine branches were various that latterly disappeared, except the existed two branches. Its coast is sensitive and dynamic due to its complicated subsystems. There was a continuous fight between land and sea in the coastal region. The sea has retreated by certain natural circumstances, which left the northern lakes in the Nile Delta region. Recently, the majority of Egypt's land is arid land, except very few parts. From these few parts are the northern lakes, besides having their valuable wetlands and high fishery production.

Burullus Lake is one of four lakes located in North Egypt, bordered by the Mediterranean Sea in the north and bordered by agricultural lands in the south, as shown in fig. 1. It exists in Kafer el-Sheikh Governorate. It is considered the second largest natural lake in Egypt in terms of the area that extends approximately 47 km in length and its width ranges from 5 to 11 km with a shallow depth (20-200 cm), its current area is about 410 km² [4]. It is connected with the Nile River by a freshwater canal (Barimbal Canal) from the southwestern side [5]. Marines and wetlands in the lake have various rare habitats. It provides society with many recreational opportunities associated with rich and rare ecosystems. In addition, it provides fishery production. There is an ecological diversity in the lake (i.e. salt marshes, plant species, aquatic habitats, migratory birds). Since 1971, this site has registered in the International Wetlands Convention known as the Ramsar Convention [6], it was classified as a seascape protected area. It has been distinguished by its spatial features, such as its location, geomorphology (e.g. plains, dunes), geology, and climate. These features have increased the economic and social values of the area. It presents a vital place for accumulated activities, such as fishing, ecotourism, and agriculture.

Since the existence of the human revolution is in many aspects of life, man has deteriorated the natural systems. The lake has its share of deterioration. It faces many stressors by human actions, besides the natural changes. Climate change is an obvious example of the natural stressors, which has impacted negatively on the lake, especially sea-level rise, and droughts. About the negative actions of a human, a vast area of the lake has been converted to fish farms and agricultural lands [7]. Also, there are seven drain pours in the lake, which discharge approximately 3904 million m³/year, including agricultural, industrial and domestic wastewater [8]. Moreover, the source of trace elements in Lake Burullus is due to the input of domestic, industrial, and agricultural drainage from human settlements, factories, and reclaimed lands in its catchment area [9]. Since 1965, pollution and eutrophication have increasingly threatened the ecosystem of the region [10]. The field studies confirmed a decrease in species numbers in the lake's area [11].



Fig. (1): Boundaries of Brullus Lake, based on Google Earth.

RESEARCH'S METHODOLOGY

The research provides an analytical study based on a case study approach. It investigates the sustainability of our environmental identity in North Egypt, particularly in the Burullus Lake, because it witnesses a high deterioration due to negative human and natural actions. Although of the increased concern with the environmental health in Egypt by many local and international agencies, the lake is still deteriorating. The study focuses on the challenges and issues that face the lake's environment, based on the observation of its current state through field visits. By addressing these challenges, it could be using the deductive method to assign the sustaining and facing actions to protect the lake. As the challenges are considered in the management cycle and planning for ecosystems and humans, the national identity will be diversified and sustained.

ISSUES AND CHALLENGES FACING THE LAKE

While social identity is influenced by behaviors, environmental identity is influenced by the quality and quantity of the natural elements. The identity could be destroyed by exposure to threats. Firstly, the lake is exposed to threats related to natural changes and disasters. The sedimentation has increased that settled on the shallow lake's bed, especially at its inlet. Moreover, the lake's coastal strip has been eroded by the action of long currents that could turn it into marine bays. As well as, the lake is exposed to desertification due to sand mobility from the closed shores. In addition, there are the impacts of climate changes induced droughts and sea-level rise. Any rise in sea level can penetrate the dunes and flood the lake. The increased temperature has caused droughts, which impacted the ecological equilibrium.

Secondly, through the field visits, it has been found that the lake is exposed to severe degradation by the human factor, which worsens the lake's health in terms of its environmental characteristics. If this degradation will continue with the same course, it could eliminate the lake's rank in terms of being a protected area at the national and global levels. The same behaviors are being in the other three coastal lakes. Accordingly, these circumstances could change or eliminate our environmental identity in North Egypt. The human behaviors that have negative impacts are intense and various, from these actions are the followings:

- Although of unused lands in the lake area, there isn't an adequate sanctuary for the lake or a buffer zone between the lake and urban areas (e.g. at Borg Al-Burullus) as shown in Fig. 2. Also, the high rate of urban encroachment on large areas of the lake's wetlands, such as in Al-Shakhloba, Borg Al-Burullus, and Hanafi and Maksaba Villages, led to the shrinking of the lake catchment through the past years. The lake has already been lost many thousands of acres. It is subject to be diminished during the coming decades if the management has a blind eye to the violations.
- Throwing of household wastes on the shores of the lake, as shown in Fig. 3. Moreover, the intense drains network that pours into the lake basin passes through the villages and receives household waste, sewage water, agricultural drainage, dirt, and industrial waste, which exposes the lake to severe pollution and water quality deterioration. Also, this network decreases the salinity in the lake, which changes the environment of the ecosystem there.
- Building and repairing ships directly on the shore of the lake, exposes the lake to pollution from manufacturing wastes (e.g. wood, grease, ...) as shown in Fig. 4.
- Penetration of the international road and its bridge in the fragile area of the lake (between the sea and the lake), which attracts the invasive ecosystems and slums expansion as in Fig. 5.
- Fishermen cut off parts of the lake basin as private property for fishing by the constructed banks as in Fig. 6. There is illegal ownership of large areas in the lake body by the owners of fish farms. Also, big fishermen prevent small fishermen from free fishing except for a few areas, under the eyes of all localities and other governmental bodies. Moreover, the illegal fishing of small fish from the lake by launches to sell them to owners of fish hatcheries and fish farms to get huge financial gains.
- The over-cutting of the reed plant for handicraft industries (i.e. mats, furniture, ...) as shown in Fig. 7.
- Sweeping the beaches and mining the adjacent soil for the benefit of the brick industry and other building works as shown in Fig. 8, which exposes the lake to inundation risk by any rise of sea level and erosion by marine currents.
- By asking the people there, it is found that there is a lack of awareness and knowledge of the society with its vital role in saving the ecological diversity to increase sustainable development.
- Drying of many parts of the lake for reclamation projects in the eastern and western parts.

- Multiple governmental entities are responsible for the lake. Also, there is poor coordination between the different governmental entities. Moreover, there are limited financial and institutional capabilities. Also, there is a lack of necessary policies, laws, and regulating standers associated with the weakness of laws implementation and wise management.
- Lack of technology and expertise. And there is a lack of knowledge and practice with management approaches related to ecosystem management.
- Disappearing of many species of aquatic plants, birds, weeds, animals, and fish, due to unsustainable consumption and production patterns.
- Over extraction of groundwater for drink and irrigation caused severe land subsidence there.



Fig. (2): There isn't an adequate sanctuary for the lake.



Fig. (3): Dumping of household waste on the shores of the lake.



Fig. (4): The wastes of ship construction and maintenance directly on the lakeshore.

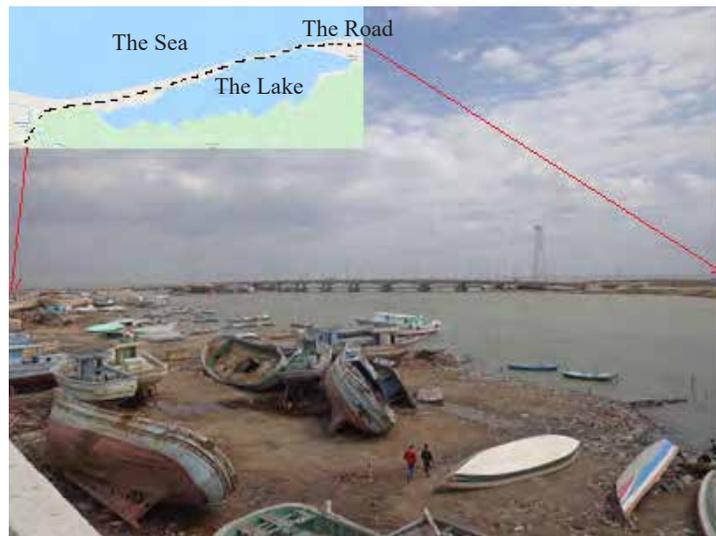


Fig. (5): The penetration of the international road and the high-pressure towers in the lake inlet.



Fig. (6): Cutting off parts of the lake basin as private property for fishing.



Fig. (7): Over-cutting of the reed swamps inside the protected environment.

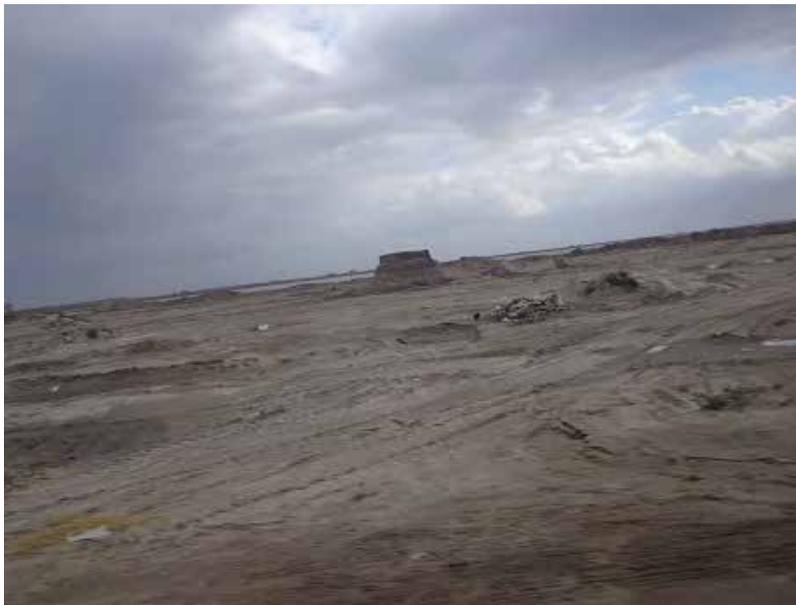


Fig. (8): Mining the lake's shore soil.

SUSTAINED AND FACING ACTIONS

The wetlands that surround the lake have environmental, social, and economic values. Due to its vital significance locally and internationally, and due to the high sensitivity of its environment to the negative human actions and natural changes, the lake should be protected by efficient management methods. It should be creating a sort of balance between these factors and lake characteristics. Through the studying visits, the human impact is more likely damaging to the lake than the natural impacts. These human actions are sourced from negative attitudes; hence it could be mitigated by promoting and training on sustainable practices in both environmental and socioeconomic considerations. Therefore, it could be facing the issues and challenges on the lake as the followings:

- The environmental considerations:
 - Zoning of the area to three zones; area of core, buffer, and transition, and setting every area with its measures and procedures.
 - Assessing and periodic monitoring of any change in the environmental characteristics of the lake. And controlling invasive species.
 - Giving high priority to the ecological systems when developing the area due to its high sensitivity.
 - Rehabilitation, restoration, and conservation of the ecological diversity in the protected area.
 - Maintaining the rare species of fish, plants, etc. in marines and wetlands of the lake.
 - Identifying the managed hunting areas, preventing the hunting of migratory birds, and cutting of rare plants.
 - Encouraging and mainstreaming of sustainable use.
 - Enhancing and mapping the visual images of the lake to promote the walkability of the area by adding landscape elements that are suitable to the local environment.
 - Enhancing the quality of sewage treatment that has been thrown in the lake in both the city of Baltim and the village of Burj Al-Burullus.
 - Enhancing the water quality of drains by strict tolerance with polluters.
 - Increasing public education and awareness of all society parts by managed environmental programs to raise the sound and positive aesthetics.
 - Comprehensive planning of the area based on sustainable development and livability basics.
 - Preserving the adjacent dunes to the shoreline and continuously feeding them to protect the barrier from the rise of sea level, in addition, using the soft coastal engineering methods.
 - Setting adaptation and mitigation programs to limit negative impacts and to take potential opportunities.
- As considering the environmental values, it should be considering the socioeconomic aspects by the following considerations;
 - Adaptive managing of the area based on an integrated approach to developing both environmental and socioeconomic aspects.
 - Strengthening and diversifying the social, cultural, and spiritual value of the place and promoting ecotourism locally and internationally.
 - Increasing the scientific experiences in the field of protected areas and engaging them in the management cycle. In addition, increasing scientific research capabilities is associated with the availability of an accessible database about the lake for research works.
 - Coordination between the responsible governmental bodies (i.e. ministries of state for environment, agriculture and land reclamation, irrigation and water resources, housing and new communities, health, defense, interior), and coordination with them and non-governmental bodies (NGOs).
 - Developing and training the institutional structure to carry out its schedule according to certain indicators to achieve the national goals.
 - Increasing the financial and technical capabilities associated with the green infrastructural network to be suitable for what is required to achieve the goal in a highly efficient manner.
 - Increasing social participation and involving stakeholders in the cycle of management.
 - Benefiting from local community experiences and knowledge.
 - Increasing economic incentives for owners of fish farms and fishermen to raise their living standards.
 - Supporting the cultivation projects of the economic plants (e.g. medical plants) that do not impact negatively on the ecological equilibrium of the area.
 - Strictly implementing the principle; the polluter must pay back to repair the damage.
 - The actual application of laws and regulations to preserve the protected area.
 - Investing in the handicraft industries that are friendly to the environment.
 - Searching for alternatives to uncleaned activities.
 - Updating Landuse planning every 5-7 years to include the additional uses based on mixed-use and compact development.
 - Encouraging volunteer groups to enhance the environment through their expertise and work.

CONCLUSION AND RECOMMENDATIONS

While social identity is influenced by behaviors, environmental identity is influenced by the quality and quantity of the natural elements. The environmental identity could be destroyed by exposure to threats. Climate change is a serious enemy to the Burullus lake's environment, its impacts are many, such as sedimentation, erosion, and droughts. From findings, human behaviors are more threatening to the lake's existence than natural threats. It is found that there is an adequate buffer zone, where there are urban encroachment, species disappearance, severe pollution, cutting off parts for various activities, mining the sand, and unwise management. To sustain our environmental identity in North Egypt, particularly in Burullus Lake, the accidental deterioration should be taken into consideration to be an environmentally conscious behavior of decision-makers, institutional bodies, and the public. By promoting and training on sustainable practices in both environmental and socioeconomic considerations, the perception will enhance our liveability, sense of place, and quality of life, as well as, it will be an environmental power to save nature to the next generations. The environmental considerations are such as zoning the area, periodic monitoring, restoration, conservation, sustainable use, strengthening the walkability, increasing the water quality, awareness, adaptation, and mitigation programs. The socioeconomic considerations are such as adaptively managing, promoting ecotourism, social participation, increasing the scientific experiences, Coordination between responsible bodies, funding diversity, the actual application of laws, cleaned activities, and volunteer groups. Finally, the research recommends the followings:

- The managed retreat of the urbanism to maintain a buffer zone or a greenbelt for the special ecosystems to protect their sensitive landscape and provide livability by limiting urban growth.
- Enacting the laws to regulate urbanism and activities expansion.
- Shifting the international road to the south of the coastal sector.
- Using the local materials to build structures (e.g. reeds, clay, rocks).
- Assessing the vulnerability of fragile habitats to different hazards.
- Creating an integrated management framework
- Setting priorities of human intervention.
- Setting the approach of local environment fund.
- Searching for alternatives for clean economic activities and green innovations.
- Committing the local community to protect the environment.
- Providing innovative methods for the waste efficient household.
- Facilitating green jobs.
- Engaging partnerships, agreements, and collaborations for saving the different habitats.
- Enhancing activities and landuse of the waterfront.

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EXPLORING HORIZONS OF SUSTAINABLE DEVELOPMENT POST-COVID-19 ERA IN EGYPT

Joint Chapter held in Collaboration with Architecture Department,
Faculty of Engineering, Cairo University



*Photographies credit:
Arch. Ahmed Hesham*

EFFECT OF SOCIAL DISTANCING ON THE RESTORATIVE QUALITIES OF OUTDOOR SPACES IN EDUCATIONAL FACILITIES: MSA UNIVERSITY AS A CASE STUDY

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ABSTRACT

Recently, High education facilities faced various challenges after the spread of COVID-19. Those challenges require resilient solutions to enhance the quality of educational experience for the wide social spectrum using those facilities.

Therefore; this study targets the possible potentials of outdoor spaces in universities in a trial of fostering the transformation it into restorative spaces with respect to the mandatory factor of social distancing to fulfill students' leisure, hence improve the experience of education.

As universities are entities with combinations of buildings and outdoor spaces; those spaces can have great potential for social and environmental transformation as they are the main location for the daily students' interaction due to their episodic effect on human prospective that people unconsciously tend to be attached to (Micheli, 2001). Sadly; after COVID-19 lock down those spaces became abundant and needed to be redesigned with respect to the mandatory factor of social distancing.

The research adopts an approach based on the restorative potentials of the outdoor spaces of various models as Marcus and Barnes's design elements of restorative environment, Kaplan & Kaplans' four factors that achieve a restorative experience, Rachel Ulrich's design resources that facilitate restoration. Accompanied by the application of Covid-19 prophylaxis guidelines proposed by HMC architects (an architectural firm), Cities-to-be (a digital platform for experts and urbanites to discuss issues related to cities) and UN-Habitat (Non-profit organization).

The choice of MSA University as a case study was due to availability of data and the wide variety of outdoor spaces for its users. The study was conducted through structured questionnaire for different target groups; so it can give the aimed results in a form of guidelines that can sustain socializing and restorative qualities within the space with respect to the application of social distancing spatially and architecturally.

KEYWORDS

Educational Facilities, Social Distancing, Restorative Qualities, Spatial Qualities, Guidelines

After the uncontrollable spread of the COVID-19 pandemic of total cases of 114,315,846 since March 2021 (WHO,2021), social distancing became a mandatory response as a safety measure to the pandemic, yet the side effects of individuals being unwillingly distanced had a negative effect on their mental health and linked to symptoms of depression , anxiety disorder, insomnia and acute stress (Marroquín, B., Vine, V., & Morgan, R., 2020), as one of the mandatory human needs is connectedness and belonging as it motivates the human overall humanitarian behavior and experience (Maslow, A. 1954). The seemingly dichotomy of fulfilling this significant factor to survive the pandemic as opposed to maintaining an interactive restorative outdoor space was the trigger of this research in an attempt to find a common ground between both facets. Hence, this research tackles this point through the study of higher education facilities and how social distancing can be applied in an effective way to serve the students need to have a successful students' life during the pandemic and provide them with a safe, restorative and interactive environment.

Since socialization is a crucial need of human daily interactions (Maslow, A. H. (1954) and can highly affect psychological aspects of human beings, thus affect the students' life experience in universities therefore it is important to look for suitable resilient solutions to overcome this problem and sustain the socialization within the outdoor spaces in university campuses with respect to social distancing as well as sustaining its restorative qualities.

The target of this study is to conclude some resilient and manageable design guidelines for a better spatial experience suitable for educational outdoor facilities to enhance its restorative qualities as well as ensuring the spatial prophylaxis factor. Moreover; the study validates those proposed guidelines through applying them on MSA October campus outdoor spaces as a case study.

The application of social distancing through enhancing the restorative qualities of the outdoor space in the educational facilities leads to a better social interaction without jeopardizing the daily students' life experience within the spread of COVID-19 or any unforeseen diseases.

METHODOLOGY

The research passed through several stages to achieve its objective. The steps shown in figure (1) illustrate the data gathering stage. This stage included the study of the various globally suggested protocols that dealt with the prevention of COVID-19. It also comprised the study of the restorative and spatial qualities of a successful outdoor space with special reference to educational facilities.

Followed by the stage of case study investigation that addresses the third pillar of the study which is the participants' spatial preferences. This part includes the study zones and the participants' feedback. This shall help in the correlation process between the two previously studied factors in the data gathering stage to generate the design guidelines based on theoretical and the guidance of user-experience perspective.

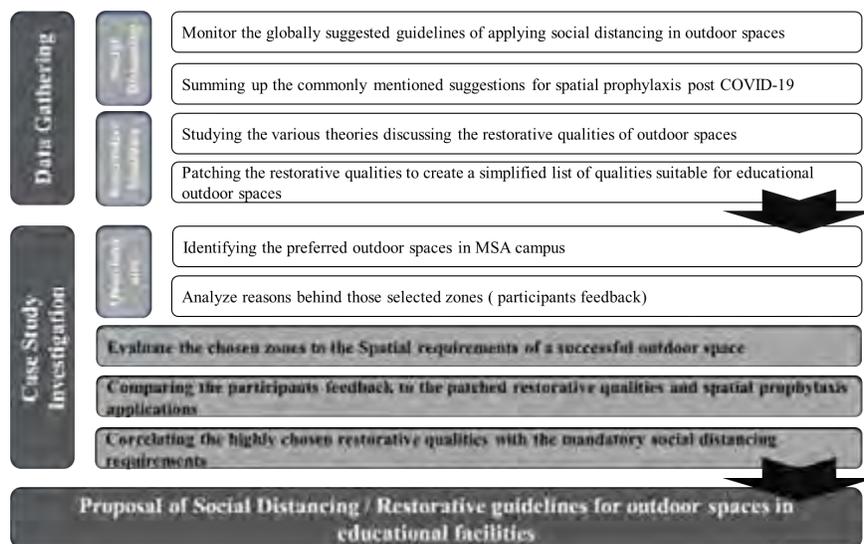


Figure (1): Research Methodology (Authors)

Literature Review

This study tackles two main topics which are the restorative qualities that can enhance the outdoor space effectiveness and the spatial factors that promotes its prophylaxis, specifically post COVID- 19 pandemic.

Firstly; the design principles used in generating a restorative outdoor space is becoming a multidisciplinary concern in the past decades, the research discusses some theories such as Ulrich’s theories, the Kaplans’ studies and finally Marcus and Barnes researches. Those theories addressed the human wellbeing and assure the enhancement of his quality of life from the perspective of listing spatial qualifications that facilitate the human’s mindful restoration process to provide a restorative environment.

As a start, Roger S. Ulrich (Ulrich, 1999) (Ulrich, 2006) listed the design resources that should be considered in designing an outdoor space to facilitate the process of human restoration. Those design resources are: 1. Control (ensure the sense of spatial control for the surrounding environment) 2. Social support (promoting social interaction over privacy) 3. Movement and exercise (the positive effect of exercise in reducing stress) 4. Natural distraction (environmental feature or situation that enhance the positive emotional state).

Followed by; The Theory of Rachel and Stephen Kaplan (Kaplan,R.; Kaplan, S.; Ryan,R.L., 1998) targets the natural environment as well as its relaxing and restorative impact on the human’s mental functioning, social interaction and overall wellbeing. They introduced some factors that achieve that restorative experience if applied in outdoor spaces which are: 1. Being away (provide an environment that allow mental distinction), 2. Extent (potential of spatial exploration), 3. Fascination (creating visually appealing sceneries) and 4. Compatibility (engage the calmness of natural environment with the daily urban environment).

Finally; Clare Marcus and Marni Barnes (Marcus & Barnes, 1999) (Marcus & Sachs, 2014) were concerned with the emotional healing of the human being and how it can be promoted from welcoming and stimulating the human surroundings which eventually aids in enhancing his/her overall wellbeing. From their point of view the following elements can promote healing potentials to outdoor spaces which are: 1. Socialization (active participation in groups), 2. Privacy (privilege of having a private spot), 3. Strolling and vigorous exercise (allowing space for activities and movement), 4.Shade and sun (this variety provide more connection with earth), 5. Choice of sitting and exploring. 6. Aesthetics of nature (highlight the beauty of nature through landscape features).

By combining and comparing the previously mentioned qualities for achieving restoration in outdoor spaces, it can be concluded that they can be patched into five bundles which are: calmness, Movement, visual stimulation, spatial control and social interaction as shown in figure (2)

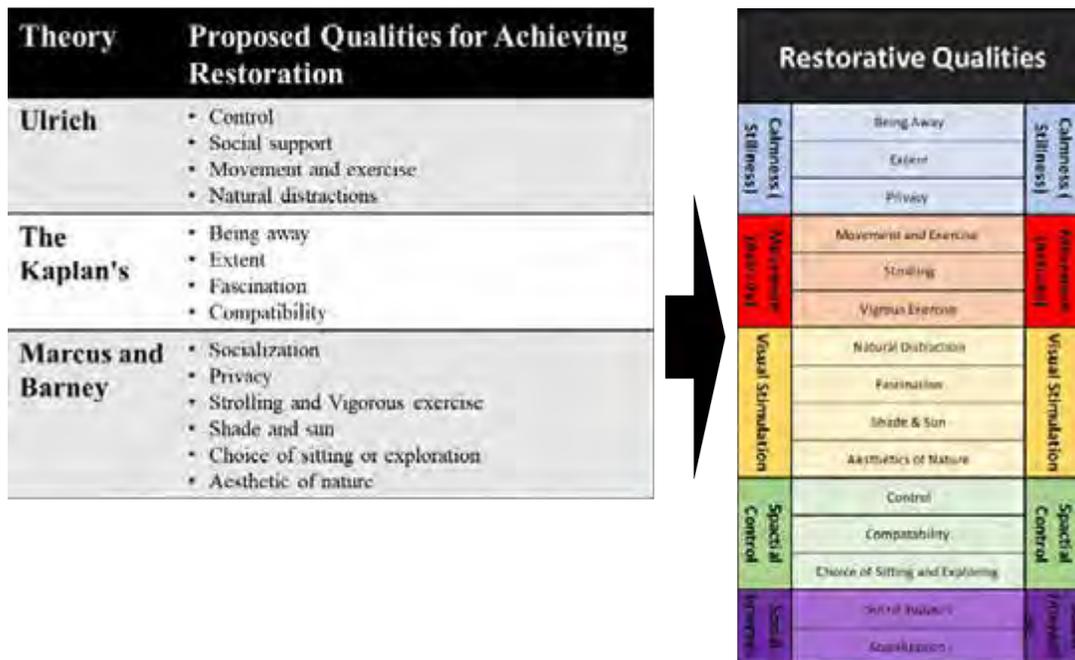


Figure (2): Proposed patching of Restorative qualities (Authors)

The Second fold of this research is the COVID-19 prophylaxis and how to sustain the outdoor space to prevent the danger of transmission. This scope of study has been trending as dealing with the sudden changes in lifestyles norms in which post pandemic is considered a paradigm shift in the design of outdoor spaces. This pillar is discussed through the highlight of three different entities with different architectural backgrounds. Those already proposed essential guidelines for a safer outdoor space during the pandemic, without the loss of human connections and socialization. These are HMC architects (an architectural firm), Cities-to-be (a digital platform for experts and urbanites to discuss issues related to cities) and UN-Habitat (Non-profit organization). Those three perspectives give a wider vision for a proper application of spatial prophylaxis.

COVID-19 lifestyle became a financial, social and cultural burden on public facilities specially facilities that requires social interaction. Starting from this dilemma HMC architects (HMC Architects, 2020) started to provide some guidelines for reusing outdoor spaces to cope with COVID-19 prophylaxis as they perceive outdoor spaces as an extension to indoor spaces and it can host activities effectively , those which are : 1. Reduce Space Utilization , 2. Revaluating and restructuring civic spaces 3. Repurposing outdoor public space.

On the other side; Cities to be (Garrido, Giorgi, González, & Tuduri, 2020) stated that COVID-19 is challenging urbanization again and they proposed some suggestions that need to be taken into consideration after reopening such as: 1. Bringing people virtually connected but physically apart, 2. Adjusting everyday life into a new norm.

Moreover, UN-Habitat (UN-Habitat,2020) argued that COVID-19 changed the relation of people with public spaces and facilities and they highlighted some gaps that can be triggered through the process of restructuring the outdoor spaces to cope with COVID-19 which are: accessibility, management, flexibility, connectivity and equitable distribution across the city.

Based on the above mentioned arguments, it can be concluded that there are some vital points that can act as essentials while dealing with COVID-19 prophylaxis shown in figure (3) which are: Reduce space utilization, Space repurposing (Flexibility), Regular Sanitization, Equalize distribution of users and connectivity with respect to distancing.

Building upon these points the empirical study can start where the procedures show the link between achieving a successfully restorative outdoor space that can cope with the pandemic prophylaxis effectively.

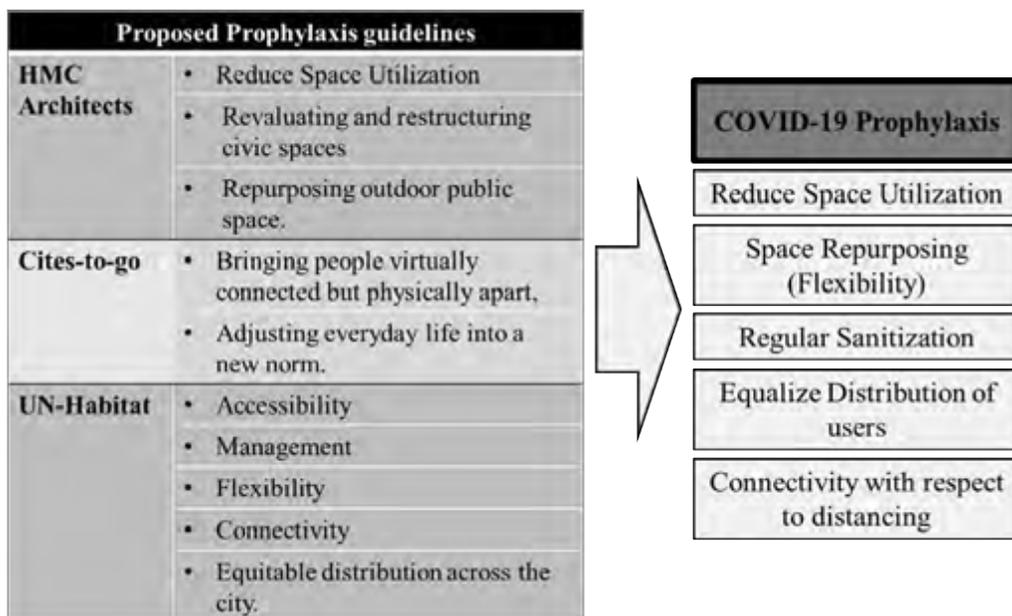


Figure (3): Proposed patching of COVID-19 Prophylaxis (Authors)

EMPIRICAL STUDY PROCEDURES

MSA 6th of October campus background

The empirical study took place at MSA University (6th of October campus), where it is known for its vast area (20,000 m²), MSA university campus is divided into seven buildings that includes different theoretical and practical schools in addition to a variety of play grounds , food court and outdoor spaces (MSA, 2021) as shown in figure (4). The study focused on the outdoor spaces and its restorative qualities and how these qualities can cope with the changes of space functionality post COVID-19 pandemic.



Figure (4): Location of common buildings used by the participants in MSA 6th of October campus (Modified by authors)

Sampling and Survey Method

The study examined some outdoor spaces within the boundaries of the campus through an online standardized survey. The survey was circulated randomly and snowballed to reach 50 participants which are classified as shown in table (1). It was circulated among students of years 3 and 4 of both the practical schools (5 years of study) and theoretical schools (4 years of study). As well, the survey was snowballed among staff who spent 2 years or more on campus. The chosen sample (students & staff) had the chance to experience the outdoor spaces in different times before and after Covid-19 lockdown due to their familiarity with campus for more than 2 years. The participants were from Buildings (C, D & E) that include some of the practical schools (Engineering, Pharmacy, Biotechnology and Dentistry) and Buildings (A & B) that include the theoretical schools (Languages, Mass communication and Management) were with relatively equal percentages as graphically presented in Table (1) and figure (5).

Table (1): Participants' Sample Classification (Authors)

| Participants' Sample classification | | | | | | |
|---------------------------------------|-------------|-----------|------------|-----------|------------|-----------|
| | Total | | Males | | Females | |
| | % | # no. | % | # no. | % | # no. |
| Participants from practical Schools | 52% | 26 | 35% | 9 | 65% | 17 |
| Participants from Theoretical Schools | 48% | 24 | 20% | 5 | 80% | 19 |
| Total | 100% | 50 | 28% | 14 | 72% | 36 |
| | Total | | Males | | Females | |
| | % | # no. | % | # no. | % | # no. |
| Staff Participants | 20% | 10 | 15% | 2 | 85% | 8 |
| Students Participants | 80% | 40 | 30% | 12 | 70% | 28 |
| Total | 100% | 50 | 28% | 14 | 72% | 36 |

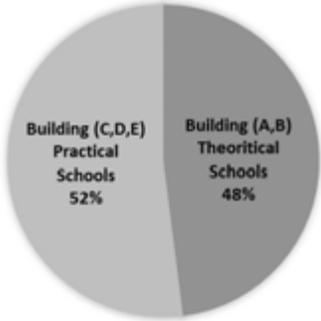


Figure (5): Participant's sample Fragmentation (Authors)

The online standardized survey was structured in two forms of questions. The first was a group of structured questions that focused on knowing their most and least preferred outdoor spots in MSA either before or after COVID-19 lockdown. The second form of questions were an open ended questions to state their reasons of choice with no reference to any factors related to restorative qualities or spatial prophylaxis to avoid bias. The questionnaire was accompanied with a guided map as shown in Fig (4) to facilitate their choice.



Figure (6): Location of the chosen most preferred outdoor spaces in MSA 6th of October campus (Modified by Authors)

The results of the standardized survey showed that the most preferred outdoor spots in MSA October Campus was firstly; the Food Court (76%), followed equally by the Market area and the road near buildings (A, B) (42%) as shown in figure (6), a more detailed description of the selected zones is clarified in Table (2).

Table (2): Description of the chosen most preferred outdoor spaces in MSA 6th of October campus (Authors)

| ZONE | Zone (A) : Food Court | ZONE | Zone (B) : Street Near Building (A,B) | ZONE | Zone (C) : Market Place |
|-------------|--|-------------|---|-------------|---|
| Map | | Map | | Map | |
| Space | | Space | | Space | |
| Description | A rectangular semi-shaded open space, with sitting areas surrounded by food vendors and a football playground. | Description | A rectangular semi-shaded open space with few sitting areas and surrounded by Building A & B and a small staff parking lot. | Description | A rectangular semi-shaded open space, with sitting areas surrounded exterior walls of buildings (C,D&E), a market shop and a small staff parking lot. |

Those zones were selected by the participants due to the following reasons as mentioned in their responses: less crowded, calmness, presence of sitting areas, good ventilation and shade, availability of social activities (meeting friends and talk), cleanness, nearness to classes and services.

Table (3) shows the participants’ reasons of choice, clearly stating that aspects are all of equal weights. The table also includes the score of each zone in achieving those aspects. The scoring is based on the count of the same response describing the same zone by different participants despite the different wording yet the meaning is similar (e.g. participants responded: clean or tidy so it can be referred to as cleanness) which showed an indication to how each zone achieved a certain reason of choice. The table concludes that Zone (A) has the highest level of achieving the reasons of choice in comparison to Zone (B) and Zone (C).

Table (3): Scoring of the participants reasons of choice for the most preferred outdoor spaces in MSA 6th of October campus (Authors)

| Reasons of Choice | Zone (A) : Food Court | Zone (B) : Street Near Building (A,B) | Zone (C) : Market Place |
|-------------------|-----------------------|---------------------------------------|-------------------------|
| Calmness | ● | ●●● | ●● |
| Not Crowded | ● | ●●● | ●● |
| Ventilation | ●●● | ●●● | ●●● |
| Shaded Areas | ●●● | ●● | ●● |
| Cleanness | ●●● | ●●● | ●●● |
| Sitting areas | ●●● | ● | ●● |
| Nearness | ●● | ●●● | ●●● |
| Services | ●●● | | ●● |
| Social Activities | ●●● | | |
| Meeting Friends | ●●● | ●●● | ●●● |

●●● Highly Achieved
 ●● Moderately Achieved
 ● Poorly Achieved

Table (3) also shows that all the zones were common in achieving a high level of cleanness, ventilation and providing a proper place for socialization and meeting friends. Yet Zone (A) was the only zone that had the potential of hosting social activities and student’s events.

Relating the participants reasons of choice to the restorative qualities of a successful outdoor space as shown in fig (7); the results show some similarities in certain factors which are calmness, visual stimulation, spatial control and social interaction, however the participants’ reasons of choice highlighted an environmental factor related to ventilation which was not listed in the restorative qualities

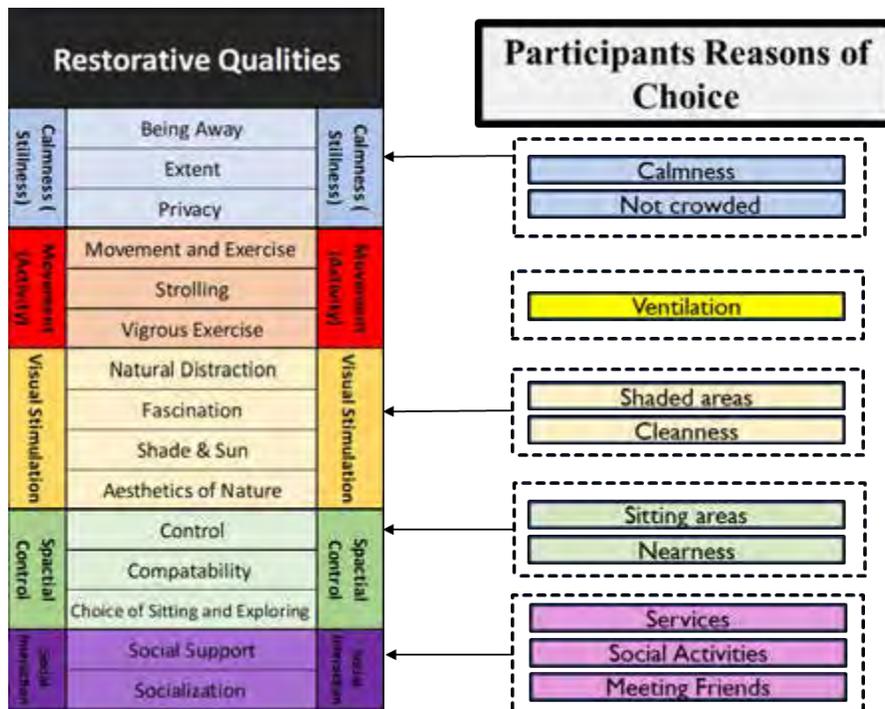


Figure (7): Proposed restorative qualities vs the participant’s reasons of choice (Authors)

On the other side; by relating the participants reasons of choice to the proposed COVID-19 prophylaxis as shown in fig (8); the results stated that all the COVID-19 prophylaxis were implemented within the participants reasons of choice yet under different terminologies but giving the same meaning and function, e.g. the factor of “Reduce space utilization” in the COVID-19 prophylaxis is similar to the reason of “Calmness and not crowded” in the participants reasons of choice.

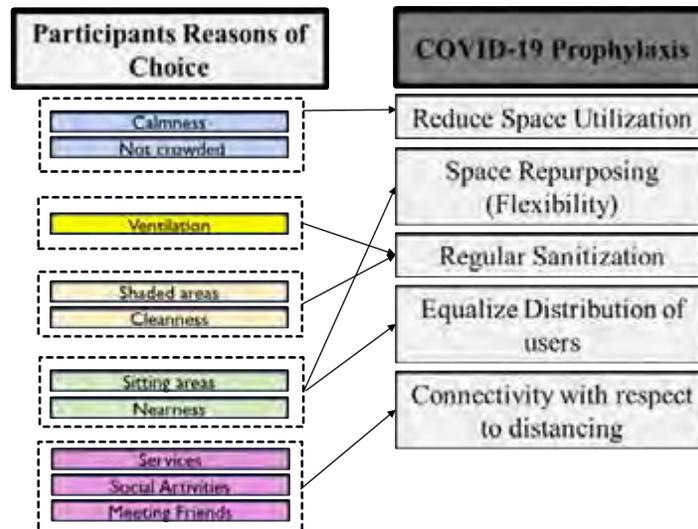


Figure (8): Proposed COVID-19 spatial prophylaxis vs. the participant’s reasons of choice (Authors)

EMPIRICAL STUDY RESULTS

The results of the case study gave some valid insights regarding the high priority human need for an efficient outdoor space in an educational facility, this feedback can be the linking point between the proposed two pillars of the research “the restorative qualities and the COVID-19 prophylaxis” as shown in fig.(9).

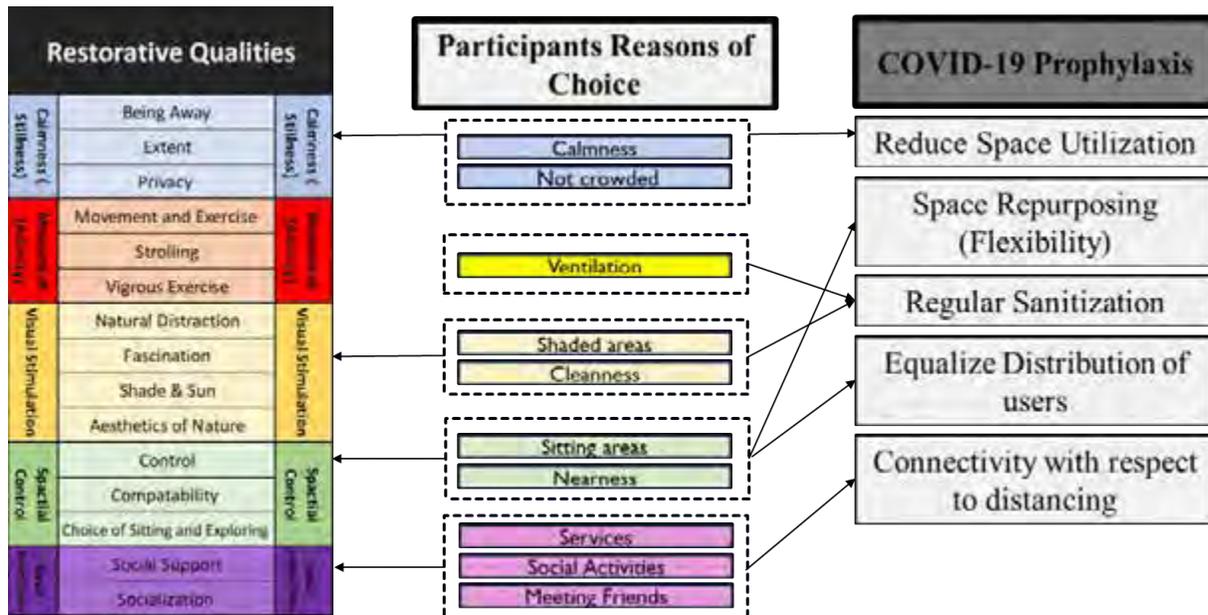


Figure (9): Proposed restorative qualities and the participant’s reasons of choice correlation vs the COVID-19 prophylaxis (Authors)

The correlations between the three mentioned factors in fig. (9) Shows that the proposed COVID- 19 prophylaxis are implemented within the participants reasons of choice including the natural ventilation factor which was not listed in the proposed restorative qualities. However; the overall results show high similarity and coherence between the three mentioned factors which accordingly gives the insights that there is a big resemblance between achieving a restorative space and creating an efficient space in terms of COVID-19 prophylaxis.

Another layer of analysis can be traced when correlating the restorative qualities and the COVID- 19 prophylaxis after excluding the users’ feedback as shown in fig. (10), the figure shows that all the prophylaxis factors are embedded in the restorative qualities e.g. “space repurposing” can be compatible with the movement factor as well as the spatial control factor. Unlike the factor of visual stimulation in the restorative qualities has no compatibility in the prophylaxis list.

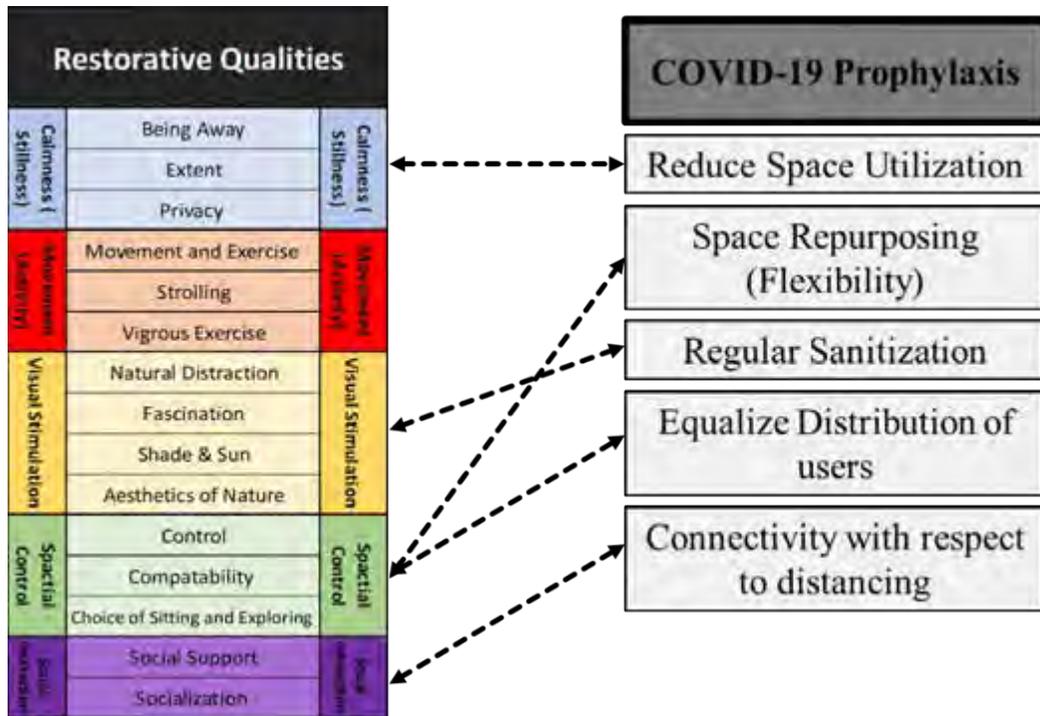


Figure (10): Proposed restorative qualities vs the COVID-19 prophylaxis (Authors)

RESULTS DISCUSSION

The results showed that the level of similarity between the three pillars of the research (Spatial restorative qualities, User’s experience and COVID-19 prophylaxis) was relatively high as traced in fig. (9). Accordingly, some spatial guidelines were proposed in table (4) as a response to the main target of the research which is to provide some guideline that can aid the educational facilities outdoor spaces to be more restorative with respect to users’ preferences and COVID-19 prophylaxis.

The guidelines are proposed architectural responses for application of social distances and other factors of spatial prophylaxis which special emphasis on the space restorative qualities and the user’s socialization needs. The guidelines were patched as reference to the outcomes of the empirical study that shows the similarities between the pillars of the research.

Table (4): Proposed Guidelines for a successful outdoor space in an educational facility with reference to restorative qualities, COVID-19 prophylaxis and users' preferences. (Authors)

| Restorative Qualities | COVID-19 Prophylaxis | Users' Feedback | Proposed spatial guidelines |
|--|---|--|---|
| <ul style="list-style-type: none"> • Calmness | <ul style="list-style-type: none"> • Reduce space utilization | <ul style="list-style-type: none"> • Calmness • Not Crowded | <ul style="list-style-type: none"> • Specify the exact allowed number of users' in each space (table/ area/ seats). • Reduce the number of seats and highlight the allowed spots that can be used. |
| <ul style="list-style-type: none"> • Visual Stimulation | <p>----</p> | <ul style="list-style-type: none"> • Shaded areas (visual manipulation between light and shade) | <ul style="list-style-type: none"> • Increase the usage of green areas and foliage to act as natural separators between areas of socialization to provide visual aesthetics, shading and semi- connectivity. • Use more creative hardscape features and furnishing that allow visual fascination and connectivity with respect to distance. |
| <p>----</p> | <ul style="list-style-type: none"> • Regular Sanitization | <ul style="list-style-type: none"> • Ventilation • Cleanness | <ul style="list-style-type: none"> • Apply a strict schedule for sanitization and provide user friendly tools for self-sanitization sustainability. • Allow a reasonable space (2m -2.5m) between the users' seating and moving areas to sustain the air flow and natural ventilation. |
| <ul style="list-style-type: none"> • Spatial Control | <ul style="list-style-type: none"> • Space repurposing (Flexibility) | <ul style="list-style-type: none"> • Sitting areas • Nearness | <ul style="list-style-type: none"> • Use mutant pieces of furniture that allow the space to repurpose easily like foldable chairs and removable tables. • Allow the connectivity between the different seating areas to be transformed into one big open space with natural lighting and ventilation in a flexible and user friendly way. |
| | <hr/> <ul style="list-style-type: none"> • Equalize distribution of users | | <ul style="list-style-type: none"> • Add guiding signs for users' for spots to use and distance to be abide with to ensure the application of social distancing |
| <ul style="list-style-type: none"> • Social Interaction | <ul style="list-style-type: none"> • Connectivity with respect to distance | <ul style="list-style-type: none"> • Services • Social Activities | <ul style="list-style-type: none"> • Provide various services spots compatible with the users' capacity to avoid congestion and long queues • Organize social activities that can be attended both remotely and in person with the same level of engagement by using remote engaging technological tools. |
| <ul style="list-style-type: none"> • Movement | <ul style="list-style-type: none"> • Space repurposing (Flexibility) | <ul style="list-style-type: none"> • Meeting friends | <ul style="list-style-type: none"> • Rearrange the students break slots and assembly hours to be distributed among the day to avoid congestion and unsafe social interaction. |

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this research paper was to come out with guidelines for the outdoor spaces in higher educational facilities, with respect to the restorative qualities and the spatial prophylaxis factor. Towards achieving this objective, the study adopted a twofold methodology. First based on the literature, while the second was grounded on a survey being applied on MSA October campus outdoor spaces.

The research concluded that there is a high coherence between the three mentioned factors. Thus, it implies that there is a considerable resemblance between achieving a restorative space and creating an efficient space in terms of COVID-19 prophylaxis. The study ends up with presenting some recommendations in the following points after proposing this set of guidelines as an outcome of the study: 1. The correlations between the restorative qualities and the COVID-19 prophylaxis can be a base point to be applied on any outdoor space with different function not only educational facilities, 2. The COVID-19 prophylaxis is in a constant update due to the unpredictable mutation of the pandemic, therefore the suggested guidelines are quiet broad and have adaptation potential.

The proposed guidelines are divided into sets that target a certain restorative quality with its equivalent from the COVID-19 prophylaxis and users' feedback; these sets can be separated into further studies for more in-depth research regarding each point to provide more detailed guideline.

The gender classification in the demographic data can be a start of a further study on the effect of gender on the spatial and restorative preferences in educational facilities

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THE CONSEQUENCES OF COVID-19 INSTIGATED RECOMMENDATIONS FOR INDOOR AIR QUALITY

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ABSTRACT

The spread of COVID-19, as an airborne virus, opened a vast set of investigations within the realm of indoor air quality (IAQ) management and control. These investigations resulted in the publication of a series of recommendations and addenda that complement currently active IAQ standards and guidelines to meet the growing health and safety concerns of building owners, operators, and users. The hypothesis stands that the airborne transmission of the COVID-19 virus implies that more stringent indoor air quality control measures should be applied. Through a systematic review of selected recently published academic journals, this article explores the intended and unintended consequences of the indoor air quality recommendations, guidelines, and standards.

Two main approaches of classifications are induced from the review: the first categorizes the consequences based on the intentionality (i.e., intended vs. unintended consequences) and temporal scope (i.e. short-term or long-term); the second categorizes consequences based on their area, namely, (1) spatial design, (2) occupants health, comfort and well-being (3) building performance and ventilation, (4) technology and energy efficiency (5) social equity, and (6) policy as well as building standards. This is one of the first reviews to explicitly emphasise the consequences of COVID-19 in relation to the addenda and recommendations of IAQ standards and guidelines, providing new insights regarding the planned and unplanned consequences. The review also highlights some gaps in the available literature that researchers need to swiftly address before institutionalizing the current health recommendations in IAQ practices.

KEYWORDS

Indoor Air Quality; COVID-19; Indoor Air Quality Guidelines; Built Environment; Buildings

DEFINING RESEARCH SCOPE AND METHODOLOGY

Introduction

The spread of COVID-19 as an airborne virus resulted in the publication of numerous investigations within the realm of indoor air quality (IAQ) management and control. The fact that occupants spend more than 90% of their time indoors, and that indoor human exposure to air pollutants is at least double that of outdoor exposure, exemplifies the need to investigate means to cater for safe and healthy built environments(1). The hypothesis stands that the airborne transmission of the COVID-19 virus implies that more stringent indoor air quality control measures should be applied.

This has resulted in the publication of a series of recommendations and addenda that complement currently active IAQ standards and guidelines to meet the growing health and safety concerns of building owners, operators, and users. However, while these recommendations aim to address the imminent health risks, they come with multi-faceted consequences related to energy, comfort, and well-being, building operation, as well as products and technology adoption.

Research objectives

This paper aims to investigate the intended and make explicit the non-intended consequences of recommendations published on IAQ in light of the pandemic. The research utilizes recent literature to study the implications of the issued recommendations on indoor air quality to achieve this. While several literature reviews have been published documenting the scientific evidence to improve IAQ during the pandemic, few published articles study the implications of such recommendations. The novelty of this research paper—and more specifically, the primary objective of this paper—is to track the COVID-19 instigated recommendations on indoor air quality guidelines and potential multi-faceted consequences such as: the well-being of occupants, thermal comfort, energy efficiency, building performance, design aspects, and technology use. The secondary aim of this paper is to understand the scientific basis for the recommended measures within air quality guidelines in the wake of the pandemic. The research also aims to understand the short and long-term consequences of these recommendations.

Research questions

This research attempts to answer the following research questions:

- What are the main recommendations within academic literature on indoor air quality published in response to the pandemic?
- What are the consequences and implications of these IAQ recommendations on building design parameters, health, occupants' well-being, energy efficiency, building performance, and use of technology?
- After reviewing recommendations on indoor air quality affecting the built environment, what are the gaps in the literature that require immediate attention?

Research methodology

The research reviewed a set of available academic journals extracted from abstract and citation databases—namely CrossRef and Scopus. The search parameters included “COVID” in the title and “Indoor Air Quality” in the keywords section. The search timeline was set from 2020 till 2021. More precisely, from March 2020, when the lockdown measures in response to the pandemic were globally enforced, until August 2021. Twenty nine articles were selected to be included within the scope of this research. They were categorized according to their scope: indoor air quality, ventilation, energy, viral transmission, simulation, pollutants, and an additional sub-category. The reviewed articles were further analyzed in terms of the recommendations they offered, and the consequences of these recommendations were thus deduced. The team of authors categorized the impact of such consequences—short-term or long-term—and whether they were intended or non-intended on a consensus based.

Paper organization

The remainder of the paper is organized as follows:

- Section II: Literature review, presenting the main findings of the investigated literature bodies;
- Section III: Discussion; and finally
- Section IV: Concluding remarks and summary of main literature gaps.

LITERATURE REVIEW

Indoor quality policy and the pandemic

Rethinking air quality legislation—and inherently IAQ—was a primary concern for policymakers at the outset of the pandemic. This notion was brought forward since air quality experts confirmed the strong correlation between air quality and the spread of the virus. Moreover, the topic of air quality policy resurfaced more when the airborne transmission of the virus was confirmed (2–5). However, in the context of the pandemic, air quality legislation appeared to be complex since there was no precedent or conclusive frameworks to follow. Thus, we can consider that air quality policy and guidelines remain experimental in focus, calling for in-depth investigations.

What has been published on indoor air quality during the pandemic?

IAQ has been tackled from a multitude of perspectives by researchers concerning the pandemic. General topic categories include policy and standards, viral transmission, ventilation, technology, simulation, and energy and building performance. These categories will make up the sub-heading of the literature review.

Table 1: Summary of Literature Articles

| No. | Paper ID | Ref No. | Summary of Findings and Recommendations |
|----------------------------------|-------------------------|---------|--|
| General Literature Review | | | |
| 1 | (Agarwal et al., 2021) | (6) | <ul style="list-style-type: none"> The paper provides a brief overview of parameters affecting Indoor Air Quality during the time of COVID with the improvement techniques in mind. The authors investigate indoor air quality literature considering the COVID-19 pandemic from multiple perspectives. An ontology chart is one product of the research paper which breaks down the parameters influencing indoor air quality. The paper presents both affecting factors on indoor air quality and improvement techniques. The improvement techniques include engineering controls such as ventilation (both mechanical and passive) and air cleaners. It also reviews the latest literature on “non-pharmaceutical” measures such as: social distancing, lockdowns, and facemasks. The paper offers recommendations for a sustainable future by advocating for the shift towards smart buildings design (to create a balance between healthy ventilation systems and sustainability—e.g., energy efficiency). The authors also recommend high efficiency air purifying filters to contribute for an improved indoor air quality. |
| 2 | (Awada et al., 2021) | (7) | <ul style="list-style-type: none"> The paper brings to light a multi-dimensional perspective on the assessment of a building’s spatial configuration in being both healthy and comfortable for occupants. The reviewed literature reviews the concept healthy buildings. Among the topics discussed are: defining healthy buildings; codes and standards and the degree by which they consider energy efficiency; the role of technology in improving building performance. |
| 3 | (Lewis, 2021) | (8) | <ul style="list-style-type: none"> The author lists the challenges of making the indoors safe commenting on the role of the WHO is issuing guidance documents and ASHRAE standards. Improving ventilation strategies is essential for a better indoor air quality—with impacts changes that are necessary beyond the pandemic. |
| 4 | (Hosseini et al., 2020) | (9) | <ul style="list-style-type: none"> The main argument put forward by this paper is that symptoms of the ‘Sick Building Syndrome’ are bound to increase during the pandemic. This is due to the increase in time spent indoors during lockdown, which consequently increases the air pollutants indoors. Indoor air pollution is attributed to several activities including cooking, smoking, and waste generation. Several brief recommendations were put forward—including regular ventilation of the household ensuring sufficient air exchange, cleaning surfaces, and using the kitchen hood for ventilation when cooking. |

| No. | Paper ID | Ref No. | Summary of Findings and Recommendations |
|---------------------------|-------------------------------|---------|--|
| COVID-19 Policy | | | |
| 5 | (Afshari, 2020) | (10) | <ul style="list-style-type: none"> Emphasizing the correlation between improved indoor air quality and better health/immune systems of a given population. Public communication—especially for the elderly—is necessary and should include aspects on indoor air quality management such as ventilation. |
| 6 | (Scotford, 2020) | (11) | <ul style="list-style-type: none"> The article brings to light justifications on why governments should shift their perception about air quality and air pollution legislation. It addresses both urban air quality and indoor air quality, and recognizes the lockdown measures as regulatory experiments. Calling upon governments to rethink the notion of ‘Clean Air’ and ‘Air Quality Law.’ Though the paper is situated in a global context, it hints at background air quality policies in the UK. |
| 7 | (Nwanji-Enwerem et al., 2020) | (12) | <ul style="list-style-type: none"> The article comments on the role of indoor vs outdoor air quality regulations, in the US context of policy. It comments on the role of the EPA. The paper contributes a set of simple preventative measures to improve indoor air quality at a household level. |
| 8 | (OECD, 2020b) | (13) | <ul style="list-style-type: none"> The policy papers make a distinction between legislative and non-legislative policies and regulations. Recommendations for improving regulatory quality during the time of COVID. |
| | (OECD, 2020a) | (14) | |
| Viral Transmission | | | |
| 9 | (Azuma et al., 2020) | (15) | <ul style="list-style-type: none"> The study presents a literature review summary on what was published to date related to environmental factors with respect to COVID-19 transmission within the indoor air quality. The literature review examines environmental factors such as: temperature/ humidity, droplet transmission methods, materials of surfaces. The paper presents case studies with a focus on Japan’s regulatory and preventative measures. |
| 10 | (Lynch & Goring, 2020) | (16) | <ul style="list-style-type: none"> The two-pager publication presents a practical technique to best adapt a room (the case study showed that of a nursing home) to improve air quality and air flow to reduce viral transmission rates. |
| 11 | (Wardhani & Susan, 2021) | (1) | <ul style="list-style-type: none"> The research paper presents a review of relevant literature on indoor health and comfort criteria that need to be revised in order to reduce infection rates of COVID within a confined space. The criterion of focus is that of the Greenship Interior Space rating system, adopted in Indonesia with a focus on the Indoor Health and Comfort. The recommendations for adjusting the indoor health and comfort criteria include:”introducing outside air, stopping air recirculation, reducing indoor user capacity, and reducing indoor biological and chemical pollutants.” |
| 12 | (Noorimotlagh et al., 2021) | (4) | <ul style="list-style-type: none"> The research paper provides a systematic review of literature discussing possible airborne transmission methods of the COVID-19 virus in the indoor air environment. The authors provide recommendations to indoor air quality experts to improve the indoor environment: <ul style="list-style-type: none"> The provision of ventilation systems, especially displacement ventilation To attempt to redesign the space with an intention to increase the existing ventilation rate and efficiency More stringent prevention and control policies (air quality and ventilation techniques) should be applied within hospital wards of COVID-19 patients in order to reduce infection rates. A recommended strategy is “isolate the COVID-19 patients with high viral loads in the exhaled air in the first weeks of infection.” Promoting social distancing – as per the WHO recommendations – and avoiding over-crowding. |

| No. | Paper ID | Ref No. | Summary of Findings and Recommendations |
|--------------------|-----------------------------------|---------|---|
| 13 | (Dolgikh, 2020) | (17) | <ul style="list-style-type: none"> The paper presents a hypothesis by which to decrease the COVID transmission rates by controlling environmental factors. The environmental factors hypothesized that are directly linked to lower rates of viral transmission include: <ul style="list-style-type: none"> Air temperature above 30C Dry weather; low relative humidity Dynamic air flow pattern The limitation of this research paper is that the hypothesis is not backed up by cited research. |
| 14 | (Anchordouqi & Chudnovskiy, 2020) | (2) | <ul style="list-style-type: none"> The research paper – written by physicists – simulates the droplet / COVID virus in an aerosol form and tracks its motion within a room. The paper concludes that the virus can stay suspended in air for hours. The simulation reveals that the virus can spread more than the recommended 6 ft of social distancing. Central air conditioning enables transmission of the virus to distant location. The general recommendation is to further research HVAC (re)design considering the viral load and air flow dynamics. |
| Ventilation | | | |
| 15 | (Ding et al., 2020) | (18) | <ul style="list-style-type: none"> The study presents the main standards / guidelines governing HVAC systems design and gives a brief overview of the HVAC preventative design measures. The article recommends the use of CFD modelling – integrating machine learning methods and AI– for more stringent and timely control of ventilation and air flow requirements within a given space. |
| 16 | (Bhagat et al., 2020) | (19) | <ul style="list-style-type: none"> The research paper breaks down the many parameters influencing the transmission of the COVID virus within an indoor space. This includes types of ventilation, types of airflow patterns, people behavior or influence within a space; droplets size and means of transmission. The discussion points are backed up by either mathematical models, visual simulation or quantitative evidence. The paper does not provide recommendations as much as it breaks down the parameters in order to understand the means of viral transmission. |
| 17 | (Tzoutzas et al., 2021) | (20) | <ul style="list-style-type: none"> The paper studies the effect of air purifiers in parallel to mechanical ventilation within a dentistry clinic. The paper shows that mechanical ventilation plays a greater role in diluting pollutants whereby the air purifiers positively improve indoor air quality by lowering PM 2.5 and TVOC. |
| 18 | (Chen et al., 2021) | (21) | <ul style="list-style-type: none"> The purpose of the paper is to provide recommendations for the ventilation of indoor spaces to reduce transmission rates of the COVID-19 virus. The authors propose a mathematical model to “determine the required ventilation rate of an indoor space based on the activity type,” and further propose “methods to achieve adequate ventilation rates.” If previous attempts are unachievable then there are “alternatives” when adequate ventilation volume cannot be reached. |
| 19 | (Lakhouit et al., 2021) | (22) | <ul style="list-style-type: none"> The research paper presents the results after comparing two scenarios for air ventilation in a hospital ward, one is determined for optimal HVAC design results. |
| 20 | (Mousavi et al., 2021) | (23) | <ul style="list-style-type: none"> The paper presents a comprehensive analysis after systematically reviewing recent literature on air circulation and air filtration within hospital settings. The paper presents both short term and long-term recommendations–retrieved from reviewed literature–to improve air circulation and filtration within hospitals. |
| 21 | (Nembhard et al., 2020) | (24) | <ul style="list-style-type: none"> The paper provides recommendations or more of a “cleaning protocol” for maintenance of HVAC systems in non-medical settings. |
| 22 | (Sodiq et al., 2021) | (3) | <ul style="list-style-type: none"> The review article presents literature findings on HVAC systems air circulation and air flow dynamics. The paper then recommends the use of innovative solutions such as the integration of “UGVI in combination with nano-porous air filter” to effectively reduce the spread of the COVID-19 virus and other harmful microbes in indoor spaces. |

| No. | Paper ID | Ref No. | Summary of Findings and Recommendations |
|--|----------------------------|---------|--|
| Technology and Simulation | | | |
| 23 | (Mumtaz et al., 2021) | (25) | <ul style="list-style-type: none"> The research paper presents the proof-of-concept study devising an indoor air quality sensors-system that detects 8 types of indoor pollutants, together with metrological measurements. The system provides real time results that are projected on the web as well as a mobile application. The proposed solution is said to “offer several advantages including remote monitoring, ease of scalability, real-time status of ambient conditions and portable hardware.” |
| Energy and Building Performance | | | |
| 24 | (Bazant et al., 2021) | (5) | <ul style="list-style-type: none"> The research paper proposes a new timeframe for mitigating indoor airborne viral transmission of COVID-19—an adaptation of an existing standard—based on carbon dioxide monitoring. The paper is supplemented by a mathematical model to enable the “prediction of airborne transmission risk from real-time CO2 measurements.” Examples are provided to showcase how the data can be presented as per the guideline requirements within university classrooms and office spaces. |
| 25 | (Anastasi et al., 2021) | (26) | <ul style="list-style-type: none"> The paper elaborates on the challenge of achieving energy efficiency and thermal comfort within “smart buildings.” The analysis of results is based on a case study/studies in the University of Pisa to aggregate environmental data. |
| 26 | (Settimo & Avino, 2021) | (27) | <ul style="list-style-type: none"> The paper emphasizes the “dichotomy between indoor air quality and energy efficiency” during the pandemic. The authors present high level strategies and recommendations of governments attempting to resolve such an impactful challenge. |
| 27 | (Aviv et al., 2021) | (28) | <ul style="list-style-type: none"> The research paper attempts to find a solution to the dilemma of maximizing HVAC ventilation within enclosed spaces and saving on energy. The research paper presents an innovative HVAC design that attempts to decouple ventilation and thermal control. The results show that: “increasing outdoor air in standard systems can double cooling costs, while increasing natural ventilation with radiant systems can halve costs.” |
| 28 | (Balocco & Leoncini, 2020) | (29) | <ul style="list-style-type: none"> The research paper studies the ventilation design of a historical school building balancing energy savings and ventilation conditions in order to reach an optimized indoor air quality scenario that ensures the sustainability of the school as a healthy building. |
| 29 | (Alonso et al., 2021) | (30) | <ul style="list-style-type: none"> The paper studies the effect of recommendations of international guidelines to “over-ventilate” with a fresh outdoor air supply especially in educational facilities. The research studies such effects on thermal comfort and indoor air quality in winter for two classrooms in Southern Spain. The research show—with regards to the analysis of standards—60 percent of operational hours cause thermal discomfort conditions. |

DISCUSSION

Consequences of IAQ instigated recommendations

Across the published literature on IAQ and the pandemic, and the general literature of guiding documents, a set of instigated consequences has been deduced by the authors. While some of these consequences are intentional, others are not. Spatial design, occupant health and comfort, building performance, ventilation and energy efficiency requirements, technology use, health and social equity, and policy implications are some of the overlapping consequences deduced.

Spatial Design

The spatial design of indoor environments is expected to be geared towards reducing the viral transmission of occupants. Published literature—in the early phase of the pandemic—touched upon the topic of spatial design in terms of the distance between occupants within a given space. This was to understand the possible means of viral transmission.

- Most of the research confirms the airborne nature of the virus. Building on such a consensus, researchers utilize simulation techniques to understand the patterns of transmission within the indoor environment taking into consideration the spatial configuration of the room—location of windows and doors—and experiment with optimal ventilation techniques to reduce infection rates (21) (5) (1,17,31). While the literature has provided many recommendations on improving ventilation to combat the pandemic, evidence to this day confirms that the complete elimination of the virus is not possible through controlling ventilation techniques alone (6) (22) (21).
- Furthermore, social distancing measures within airtight buildings is scientifically proven not to be an effective measure—or at least in eliminating viral transmission. As shown by Anchordoqui et al. [8] the virus is not bound to the 6ft social distancing recommendation. This means that other variables must come into play to decrease infection levels. Therefore, it is evident that the health of occupants has become the primary objective of researchers following the pandemic.

Architects and designers will also be taking the occupant health as a priority when constructing buildings and retrofitting existing ones. Thus, it can logically be deduced that the number of occupants within a space is expected to decrease—i.e., number of occupants per built-up area. Maybe a rule of thumb for the near future addenda of spatial design codes and standards of medical and non-medical facilities will be communicated clearly rather than implied.

Moreover, the requirements for social distancing and decreasing the number of occupants within a given space would inherently mean that the spatial zoning needs are to cater for more isolated spaces, with more reliance on natural ventilation if possible. For example, in office spaces, moving away from open working spaces to sheltered single—or small number of occupants—offices is evident. Another example is in a medical setting, the large open space zones— whether in waiting rooms areas or in large wards—would not be a preferred design. The same applies to commercial spaces. Whether restaurants or retail shopping centers, a more outdoors-oriented setting would be a preferred design. Schools—and educational facilities in general—are yet another building typology—like offices—that would move towards smaller spatial requirements per classroom, to host a small number of students per classroom. In addition, the logical concept of increasing building permeability and reliance on both natural and mechanical ventilation would mean designers would move away from the smart buildings trend—that are characteristically air-tight—or at least challenge the building envelope to adapt to IAQ guidelines.

Occupant's Health and Thermal Comfort

Health over comfort. This is what can be learned from the recently published literature and guidelines. Overall, if guidelines are to be followed to the letter, occupants are to spend most of their indoor time in thermal discomfort— especially in the winter season.

Not only is the physiological health of occupants becoming a priority to policy experts and researchers, but also their psychological state and wellbeing. For instance, the isolation of spaces has unexplored implications on well-being, including anxiety, stress, and depression. Safeguarding occupant's health, wellbeing and comfort is a multi-layered endeavor in the context of IAQ.

- As summarized by Agarwal et al. (6) in the form of an ontology chart, there are a number of factors and AQ parameters that affect occupant's safety post the pandemic. Such factors were grouped by the authors into “affecting factors” and “improvement techniques.” The affecting factors include ambient air quality parameters (PM_{2.5}, PM₁₀, NO_x, SO_x) and related monitoring methods and AQ index. Thermal comfort falls under environmental air quality and includes the sub-parameters of relative humidity and temperature. The improvement techniques include the non-pharmaceutical options (social distancing, lockdown measures, and facemasks), as well as engineering controls of ventilation and air cleaners. The review paper brings to light the importance of tackling the issue of health and thermal comfort of occupants from several fronts: ambient air quality parameters, ventilation modes, policy and behavioral aspects, as well as the added layer of monitoring such parameters.
- Alonso et al. (30) discuss the thermal comfort—or rather discomfort—scenario for schools in winter, where opening the windows is a mandatory recommendation to secure the health of young children in primary schools. The study compared the results of environmental measurements of two classrooms in a primary school in Spain before and during the pandemic. The results showed that when the windows were open, the ppm levels within CO₂ measurements were reduced. However, relying on natural ventilation in winter means that 60% of the time, students are in a state of thermal discomfort. Thus, thermal comfort is becoming a secondary priority to health.

- Alternatively, Balocco et al. (29) discuss the added challenges of retrofitting a historic school building to meet the requirements of re-opening schools after the lockdown, and in the meantime achieving the balance between energy consumption reduction, occupants health and safety, and environmental sustainability with respect to IAQ requirements. The software simulation carried out by the authors considered the existing plant as the baseline scenario, another scenario considered retrofitting the building to reduce air infiltration rates, and glazing factor; and 8 other scenarios were simulated with varying capacities of HVAC systems. The results showed that carrying out retrofitting activities of windows and doors yielded higher results on investments. On the other hand, when considering HVAC systems the intermittent air temperature control modes related to specified air exchange rate was the optimal combination for energy savings. The historic school case study sheds light on the importance of taking into consideration the physical conditions of the buildings, and not to focus solely on investing in high-efficiency ventilation systems when the fiscal resources are available.

Achieving such a delicate balance between health and comfort is difficult, and considerably challenging when considering the financial considerations of energy savings as another parameter to the equation.

Building Performance and Ventilation

The call for blasting HVAC units, increasing ventilation rates, and adopting the latest air purifiers technology means that occupants' comfort and health will always be a competing priority with energy efficiency standards. The consequences of such an already existing debate are that more advancements in HVAC design will take place to balance energy efficiency performance, air purification, and filtration.

Moreover, central HVAC units are to be reconsidered in principle if occupants' health remains a top priority. Literature has shown that viruses can be transmitted to a much wider distance than the promoted 6 ft social distancing guideline in the presence of centralized HVAC units.

Many of the reviewed papers attempt to assess the impact of mechanical ventilation on reducing the rate of viral transmission. Medical facilities receive special recognition in the reviewed research work given the nature of the facilities where the infection rates are high, and the need to contain the contamination within a specific area is even greater. The IAQ recommendations also point towards depending heavily on air purifiers and mechanical ventilation systems for improved levels of IAQ.

- Sodiq et al. (3) review literature concerned with the “indoor airborne nature of infectious microbes,” presenting historical examples on airborne communicable diseases and the means by which the virus was transmitted given the HVAC/ventilation conditions. The study reinforces the concept to design the ventilation system with the purpose of confining the air to a specific area so as not to spread to other occupants. As an example the air circulation of the pilot's cabin is confined and is separate to that of the passengers' area on an airplane.
- Tzoutzas et al. (20) study the effect of mechanical ventilation and air purifiers within a dental clinic in Athens in its role in maintaining improved IAQ levels. The performance of air purifiers was assessed by monitoring the levels of PM2.5, PM10, VOC and CO2. The efficient role of air purifiers was confirmed by noting the reduction in the levels of PM2.5. Another study conducted by Mousavi et al.(23). thoroughly reviewed air filtration and air recirculation mechanisms. The study confirmed that there are means by which to reduce the load of viral transmission by using a combination of high efficiency air purifiers, whether portable or within an integrated design with the mechanical ventilation system in place.
- Lakhout et al. (22) questions the overstated causality that improved ventilation within indoor environments—and hence energy requirements —reduces viral transmission. Two scenarios within a hospital setting are simulated: 60m3 rooms following the ASHRAE guidelines on ventilation and using Fire Dynamic Simulator (FDS) as the contaminant being emitted by the patient. Comparing the results of PPM levels and estimates on indoor air quality yielded that the scenario featuring a closed quarantine room hosting the patient showed more promising results. The paper provides a useful reference for testing IAQ scenarios to determine the optimal settings for ventilation and contaminants control.
- On the other hand, Bhagat et al, attempted to breakdown the patterns of air flow within the indoor space, distinguishing between the different types of ventilation (mixing ventilation, natural and mechanical displacement, wind-driven ventilation as well as stratification) (19). Such distinctions between ventilation types—with the aid of mathematical models—were the method used to further assess the effect of people in an indoor space and how the virus is transmitted. The study relied on “synthetic schlieren” images in order to detect the movement of air. The authors observed that it is reasonable to consider CO2 detection as a reliable indicator for exhaled air.

As such, the rhetoric studying the role of mechanical ventilation in improving IAQ is enough evidence that energy consumption patterns are likely to surge as a consequence. Notably, innovations are underway to tackle the resultant energy inefficiency issue.

- Aviv et al. (28) demonstrated that cutting energy costs is possible while relying on 100% clean air intake in HVAC systems. Instead of depending heavily on natural ventilation, radiant systems have been proposed as an alternative cooling strategy rather than air-based systems. Radiant systems depend on infrared radiation that is exchanged between occupants and the surrounding surfaces in the indoor environment (28). Energy costs were estimated by the authors to be cut by half, marking them as especially relevant to humid environments (28). Such savings, with varying rates, were shown to be positive in climatic zones around the globe.
- Another means to practically improve the ventilation performance of HVAC systems is through performing a cleaning protocol and maintenance, as proposed by Nembhard et al. (24). This, in retrospect, will translate to more energy efficient performance.

Another, deduced consequence is related to the carbon footprint of buildings, which is expected to increase as per the dual ventilation modes recommendations.

Technology Use and Energy Efficiency

One more evident observation is that technology will play a more powerful role in monitoring IAQ parameters to decrease viral transmission and improve the energy efficiency of installed ventilation systems.

- The research paper “Internet of Things (IoT) Based Indoor Air Quality Sensing and Predictive Analytic – A Covid – 19 Perspective” by Mumtaz et al. is just one example of how IAQ innovations can contribute to improved energy efficiency by optimizing HVAC systems (25). The paper proposes an IAQ monitoring and predictive analytical solution of IAQ contaminants.
- Similarly, Anastasi et al. propose a method of IAQ management in smart buildings by utilizing an interactive method with occupants, by tracking location and CO₂ concentrations in order to improve HVAC operations (26). Likewise, Bazant et al. make use of monitoring CO₂ concentrations in the built environment in order to quantify infection rates post the pandemic (5).

With the aid of AI dynamic sensors that follow occupant’s movements, in what was brought forward in the smart buildings’ discussion, these will be yet another means to monitor IAQ, energy efficiency of ventilation systems, and alert users in case contamination is detected. The consequence of such technological direction implies that open access data and its social privacy implications are another aspect to consider.

Privacy is a fundamental concern when it comes to big data analysis methods to IAQ monitoring. Tracking the location of users within and without buildings as a means of controlling infection rates has provoked human rights organizations across the globe. However, from a research perspective, such innovations and precise dynamic information is a means to safeguard the health of occupants.

A rather important deduction pertaining to IAQ recommendations in light of the pandemic, is the energy inefficiencies resulting from the particular recommendations of blasting ACs along natural ventilation requirements (27). At a first glance, building ventilation requirements (mechanical vs. passive) are perceived as a dichotomy. However, the dual mode of ventilation is meant to be in complementarity mode to maximize clean air flow and circulation.

- Ding et al. (18) make the point that conventional ventilation – both passive and mechanical – is meant to increase the clean air inflow to the indoor environment, consequently decrease the contamination levels, and to an extent maintaining thermally comfort environments (18). Ding et al. (18) expressed that HVAC designers would need to balance between a healthy indoor environment and the building’s energy. The review paper is primarily concerned with reviewing ventilation engineering controls of health facilities and public transportation vehicles.
- Chen et al. (21) provide practical examples with numbers on the cubic meter per hour per person (CMH/ person) based on reviewed guidelines amongst which are the WHO, ASHRAE guidelines, and US-CDC. The ventilation volumes required are evidently far from efficient.

Moving forward, the HVAC industry will indubitably witness an exponential surge in innovation in the design of HVAC systems. This can be through increased efficiency, maximizing clean air inflow, circulation patterns, or integrating high efficiency air purifiers. These are only a few of the upcoming contributions.

Health and Social Equity

A less touched upon the topic is the social equity implications of relying on technology that is not yet affordable – to improve IAQ and mitigate viral transmission. The argument of the lack of social equity is strengthened by the spatial requirements of more individualistic spaces which might not be an affordable option for the larger community.

- Scotford (11) brings the affordability dimension of gearing the ventilation of buildings towards full reliance on mechanical ventilation to the forefront.
- Awada et al. (7) discuss the economic consequences to unhealthy buildings. While there are direct costs incurred in terms of energy inefficiencies, the indirect costs related to occupants' health are much higher. For example, productivity levels in an office building will be affected with the higher number of sick-leaves, employees turn-over rates, and loss of focus in an uncomfortable and unhealthy indoor environment. In other words, there are socio-economic consequences to unhealthy buildings. As such it is perceived to be an unintended consequence that would have long-term effects.

The social equity challenge is not limited to residential accommodations but to most building typologies. For instance, hospitals during peak seasons of the pandemic were overcrowded; this meant that keeping up with high quality standards such as in the isolation wards or ICU units was not realized in all other hospital zones.

Policy Implications and Rating Systems

Considering guidelines as part of the soft policy interventions, there is a lot to be said about the implications of IAQ guidelines published during the pandemic on the long run. Guidelines are continuing to be written in a temporary spirit, assuming that the pandemic is a short-lived health hazard. The question is: what if it is here to stay? In other words, one of the lessons learnt from the pandemic is the ease of viral transmission within enclosed areas. With that taken into consideration, guidelines need to be written with much clearer language to account for long-term affordable solutions that can be universally applied.

The green buildings rating systems also act as complementary guidelines. Currently published certification systems, such as LEED, do not offer much for healthy and well-ventilated buildings in the proposed capacity of IAQ recommendations. Most of the published rating systems were focused on the other end of the spectrum, namely energy performance, which contradicts current IAQ recommendations focus of healthy buildings and healthy occupants in the new normal post the COVID-19 era. Other standards, including WELL standards (29), which are more focused on wellbeing, might gain more ground.

However, there is evidence that changes within green buildings certification systems are to take place in the near future to emphasize the health and comfort needs of occupants.

- The paper by Wardhani (1) is an example of how to adapt rating systems to health and comfort needs. The paper proposed adaptation strategies to an existing building certification system: GreenShip Interior Space, within the Indoor Health and Comfort (IHC) criteria which was an example of how to appropriate existing green building rating systems to improve the IAQ and reduce infection rates. The newly introduced adaptation strategies were based on recent literature proposing recommendations for improving IAQ levels and promoting the health and comfort of occupants. While the paper focused on office spaces, the recommendations communicated are easily applicable to (non-medical) indoor spaces hosting a large number of occupants.

Potentially, new rating systems will emerge to allow for a new label of airborne safe buildings, though the evidence is yet early to concur with the “the rise of new rating systems.”

Impact and intentionality of IAQ instigated recommendations

As the basis of its discussion, the research paper documented and analyzed the key published recommendations for indoor air quality practices in the wake of the COVID-19 pandemic. The analysis was conducted using a qualitative descriptive approach categorizing the type of recommendations. Furthermore, **Table 2** provides a summary of the perceived consequences to the published IAQ recommendations, distinguishing between intended and not intended consequences of such recommendations. The distinction between long term and short term impacts is essentially a conceptual time limit. Long-term is in the range of >10 years, whereas short-term is in the range of 1-3 years.

Table 2: Instigated Consequences Related to IAQ and COVID-19 Reviewed Literature

| Category | Consequence | Based on (Reference) | Expected Impact | | Type of Consequence | |
|---------------------------------------|---|----------------------|-----------------|-----------|---------------------|--------------|
| | | | Short-term | Long-term | Intended | Non-Intended |
| Spatial Design | Reducing viral transmission | (4,8,17,21) | | ✓ | ✓ | |
| | Number of occupants decreased within a space | (7,21,26) | | ✓ | | ✓ |
| Occupant's Health and Thermal Comfort | Prioritizing physiological health of occupants | (1,7,29) | | ✓ | ✓ | |
| | Thermal comfort becoming a secondary priority to eliminating or reducing viral transmission. | (15,30) | ✓ | | | ✓ |
| | Building certification systems might have a larger market in the future | (1,7) | | ✓ | | ✓ |
| Building Performance and Ventilation | Energy inefficiencies as a result of excessive reliance on HVAC systems | (26–29) | ✓ | | | ✓ |
| | Increase of carbon footprint of buildings | (26–29) | ✓ | | | ✓ |
| | Social distancing may not be an effective precautionary measure in indoor environments relying on mechanical ventilation. | (2) | ✓ | | ✓ | |
| Technology Use and Energy Efficiency | Unintentional invasion of privacy due to dynamic monitoring aspects | (25) | | ✓ | | ✓ |
| | HVAC design innovations | (3,18) | | ✓ | ✓ | |
| | Energy in-inefficiencies | (26–29) | ✓ | | | ✓ |
| | Increase in carbon footprint of buildings | (26–29) | ✓ | | | ✓ |
| Health and Social Equity | (Un)Affordability of solutions to decrease viral transmission (technology use and mechanical ventilation) | (11,13,14) | | ✓ | | ✓ |

CONCLUDING REMARKS

Maintaining an acceptable—ideally optimal—level of indoor air quality is fundamental to promote the health and comfort of its occupants. To that end, the research paper presented synopses of recent literature that discusses the impacts of the pandemic on indoor air quality, with a special focus on the foreseen consequences of recommendations within published literature on IAQ. Several key knowledge topics have been identified as study areas which would complement the body of knowledge on how best to achieve sustainable indoor environments by proper management of IAQ, which include: spatial design considerations, occupants' health and comfort, building performance and ventilation, technology use and energy efficiency, as well as health and social equity.

The pandemic set a revolution on IAQ research, and it remains a work in progress:

- While the issued guideline documents during the pandemic are considered a temporary intervention; the recent medical evidence suggests that the virus and its evolving variants are here to stay (40). This suggests that prioritizing health will remain a permanent shift within issued standards and guidelines. Notably, social distancing and the implications of decreasing the number of occupants within a space has yet to see a more substantial presence in building standards and codes.
- This realization urges authority associations and organizations to advance standards and guidelines with primary objectives that integrate both health priorities and sustainability aspects. Finding the balance between energy cost=effectiveness, economic use of resources, social dimensions, and the health and comfort of occupants will be the challenge for current and future policymakers in an attempt to issue a comprehensive indoor air quality standard(s). A simple, straightforward existing dichotomy is the call for maximizing ventilation and filtration while paying minimal attention to the energy costs such operations incur.
- With reference to tech-use in monitoring IAQ parameters, innovations utilizing dynamic sensors and AI technology will have more influence in the future. Commercializing this technology for broader use with a focus on affordability and ease of utilization is a project that will come to light in the near future.
- Although the research on optimal design for the HVAC ventilation systems and air purifiers is picking up, there is still no affirmative answer on what to expect on energy efficiency performance on the long run.

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PLACE(RE)MAKING FOR A MENTALLY HEALTHY CITY: SPONTANEOUS ACUPUNCTURES AT CAIRO'S PARKS AND THEIR RELATION TO COVID-19

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ABSTRACT

Given the Egyptian capital's dense urban condition and minimal green spaces in return [1], Cairo requires a surgical intervention in the few existing green parks to respond to citizens' needs for well-being and stress relief. Globally, mental health is acquiring bigger magnitude in planning and developing cities. Incorporating subjective well-being measures in urban settings aims at inducing positive experiences to the city's dwellers [2] and contributes to its quality of life [3]. The paper hence traces the contemporary history of two agency-led grassroots initiatives tackling well-being from both mental and physical perspectives; in al-Azhar Park at Cairo's historic core and Merryland Park in Heliopolis. The selected urban youth initiatives include yoga and cycling infrastructure activists. Through a set of semi-structured interviews with 3 yoga instructors and non-participant observations during the 2020 lockdown, and thereafter, we argue that such practices fall within the framework of urban acupuncture albeit in an unplanned spontaneous manner. Therefore, the study recommends including such needs-driven initiatives in the governance of urban parks and in coordination with the municipality, fostering those efforts for a wider impact. This paper aims at positioning Cairo with the emerging discourse of mentally healthy cities as depicted in the World Health Organization (WHO) global meeting at Oman in December 2019 [4], and following the UN-Habitat's 3rd Sustainable Development Goal (SDG) "Good Health & Well-being" [5].

KEYWORDS

healthy city, urban acupuncture, green parks, yoga, bicycle urbanism, Cairo

INTRODUCTION

During the pandemic, many cities called for the return to nature and mother Earth stressing on the mental well-being of humans. These calls included healthy diets, meditation, allowing time for personal space, reclaiming green spaces, walking alone, social distancing, exercising and endorsing a minimalist lifestyle. Many experts saw the outbreak of SARS in 2003 and COVID-19 with Wuhan's food market as conspicuous signs of humans' profusion to other spaces and species [6,7,8]. The pandemic raised the question of density, and whether over-crowdedness was a factor in exacerbating the spread of COVID-19. What is the right percent of urban density, or it is relational to health infrastructure and support systems of caring from the family, to the nuclear and extended family to the neighborhood then municipality levels. All these issues surfaced on the academic level creating a schism around urban planning, masterplans, healthy procedures, urban governance that need to be attuned to citizens and their user-experiences [9,10].

In Cairo, there are a handful of green public parks that are insufficient to balance the increasing rates of noise pollution, air pollution, carbon gas emissions and urban stress [11,12,13]. The recent pandemic pushes us to rethink the usage of green public spaces and the incessant task of expanding their foot print in our congested city. Retooling public green spaces and their infrastructure to address the intangible implications of stress, mental health and well-being caused as a result of dense cities, ill-management of their spaces, health conditions, and absence of breathing spaces such as parks, or life patterns, etc. requires further studying.

The eventuality of the pandemic as a moment of crisis yielded in people improvising and remaking spaces, and developing infrastructures of caring in society as AbdouMaliq Simone puts it [14]. This manifested in Cairo through many activities and social networks that emerged during COVID-19 such as: outdoor cinema, rooftops gathering, and car-trunks' hangouts [15]. The discussion here presents "urban acupuncture" as momentary solutions, but at the same time the presence of "urban activism" and "grassroots movements" for well-being often picking the fragments of decaying and dysfunctional infrastructure [16]. People are the infrastructure for exploring new catalysts in the city, recounting, retooling and re-operationalizing spaces. Writing about African cities, Edgar Pieterse tells us: "I have no doubt that the street, the slum, the waste dump, the taxi rank, the mosque and church will become the catalysts of an unanticipated African urbanism" [17].

This paper starts by highlighting the positioning of mental health and well-being in WHO and SDGs reports, then analyzing the nuanced practices of urban youth during COVID-19 in multiple open public spaces at Cairo. The authors show some of the parks used for mental health and stress relief during the pandemic in Table I and Figure I. Then the focus turned to al-Azhar and the Merryland Parks in particular as two urban acupuncture; and as two exemplar role models in Cairo. As an interesting observation that will be depicted later in the discussion and finding, the size of the park is indirectly proportional to its capacity to host activities promoting well-being. In fact, among the parks explored, the smallest size "Golf & Dog Park" in the midst of a highly dense neighborhood according to CAPMAS numbers, has been the most viable and comfortable space for people to practice meditation and yoga, more so than wide and spacious parks such as Al-Azhar Park, the Merryland Park, and Family Park. The reasons behind such finding goes beyond the scope of this paper. There are a set of intertwined variables that are involved including security, governance and parks administration, residents' perception, community support and engagement, etc., which can be explored in a future research as a recommendation. However, what we explored is that "urban acupuncture" and well-being activities are effective in green parks despite of their scale and over densified neighborhoods.

Table I Egyptian parks registering wellbeing activities [18,19,20]

| Park (Area) | Administrative District | District Population |
|-----------------------------|-------------------------------------|---------------------|
| Al-Azhar Park (74 acres) | Al-Darb Al-Ahmar, Cairo Governorate | 60,989 |
| Merryland Park (45 acres) | Heliopolis, Cairo Governorate | 139,856 |
| Golf & Dog Park (4.2 acres) | East Nasr City, Cairo Governorate | 661,907 |
| Family Park (70 acres) | New Cairo, Cairo Governorate | 310,087 |



Figure 1 Researched Parks' locations across Cairo [21]

The main objective of the study is to reframe a new urban agenda for mental health and well-being in Cairo's few green spaces and urban parks through encouraging, adopting and cooperating with already existing grassroots initiatives on the ground. The main argument is that placemaking needs to become an "interdisciplinary design process" engaging grassroots and initiatives addressing intangible dimensions affecting the physical place such as well-being and mental health. There is enough literature on placemaking, but we need a leverage for place(re)making that builds on activists' efforts for a better environment and an engaging place.

Towards understanding how "urban acupuncture" are re-injected in some of the existing green parks during the pandemic, we have conducted a set of semi-structured interviews with leading yoga instructors that initiated meditation exercises at Al-Azhar Park, Merryland Park, Family Park and Golf & Dog Park, situated those practices within an "urban acupuncture" approach of small-scale intervention with the aim of large scale impact together with analyzing the World Health Organization (WHO) report for the condition of well-being as a Non-Communicable Disease (NCD) in the global South [22].

Our methodology involves rethinking place as a *re-place* at times of crisis using two genres of urban acupuncture [23], intangible: free yoga classes at Al-Azhar Park, and tangible catalyst: cycling and sports installations at the Merryland Park [24]. We explore how initiators and residents reuse underutilized spaces and infrastructure. The idea is to expand urbanism to connect, incorporate, learn and engage from activities on the ground to ameliorate the physical space through intangible catalysts of health and well-being for *place(re)making*. In other words, our methodology is to spatialize the intangible presence. Placemaking is not a linear design outcome, or a singular victory for change. It requires constant efforts to ensure its efficacy and continued sustainability at the local and neighborhood level. Place(re)making is a dynamic process of unlearning and relearning to enhance space. The process is centered around how we can always do better with limited resources. Through re-learning about green space from yoga activists and residents' approbations with their struggles to find space, we contribute to the research domains of urban acupuncture for mental health and well-being in the global South.

MENTAL HEALTH & URBANISM

Quality of life is measured by a range of factors, including subjective and objective well-being [25]. Mental health is one of the variables affecting subjective well-being. Multiple studies have shown that the risk for critical mental problems is generally higher in cities compared to rural settings [26]. Researchers are calling for renewing our spaces towards "mental health friendly cities" and developing strategies at the level of urban planning, decision making, top-down and bottom-up [27,28]. In December 2019, the WHO organized a forum in Muscat, Oman to tackle SDG 3.4 [29] that addresses mental health, well-being and the Noncommunicable Diseases (NCDs) such as cardiovascular diseases, cancer, chronic respiratory diseases and diabetes as they

represent a threat to low- and middle-income countries. NCDs (mental health included) are responsible for 40.5 million out of 56.9 million deaths in 2016, meaning about 71% of the global mortality and mostly located in the global South [30]. The director of the department of Mental Health and Substance Use at the WHO, Devora Kestel highlighted that working with the ministries of health across nations is not enough and this must encompass everybody “to work on mental health reform for a range of conditions across levels of the system” [31]. The statement reverberates the importance of engaging existing efforts on the multiple scales of space. Examples from many countries embrace interdisciplinary approaches to activate space. In Bangladesh, Saima Wazed Hossain, Chair of Shuchona Foundation expressed that a new mental health plan will generate “community clinics” to bridge the parity between physical health and mental health through developing a platform for “community-based mental health and psychosocial support services” [32]. Another example from Zimbabwe is to scale up the “Friendship Bench”, which is based on neighborhood initiatives and round-the-corner spaces run by lay health workers and grandmother [33].

Urban wise, the city affects the mental state of its dwellers [34], so in compilation with the UN-Habitat’s New Urban Agenda (NUA), and Sustainable Development Goals (SDGs), this study addresses the 3rd and 11th SDGs “Good health and well-being” & “Sustainable Cities & Communities” respectively. As a result, the question of retrofitting underutilized infrastructure and rescaling grassroots efforts based on “collaborative care” that are already existing despite the limitation of space, resources and governance’s low-impact at the local level need to be mobilized in Cairo. In the next section, we will reflect on two attempts of catalyzing existing parks and outdoor sports installations to address mental health and well-being “bottom-up”, away from the state. We theorize those initiatives as experiential learnings of urban acupuncture.

Studying those initiatives shows that public parks do not become *public* or *parks* by the virtue of allocating green covers and aesthetically appealing design elements for views. A good design offers an opportunity for a couple of outings, an engagement with the park on basis of being a tourist and passerby. To connect and engage with the greenery space require a level of bondedness in a sustainable manner that transcends mere aesthetics to include conscious ethics of the positionality of the self and the surrounding. And this is what the paper argues for with the need of a continued urban connectivity by *giving back*, and “urban kindness” to establish a nourishing relationship between the self, place, and people in a growing competitive metropolis such as Cairo.

SPONTANEOUS ACUPUNCTURES

The term “urban acupuncture” recently grew as a creative approach of “small scale” intervention to tackle the city and its inherent problems. The term emanates from the Chinese medical treatment of needles that are carefully inserted in certain spots in the human body to dispose blood clots, pain, injury, fatigue and enhance energy flows throughout the body. It works through exerting pressure in selected spots to leave a wider impact. Coining “acupuncture” with “urbanism” first appeared in the US in the last 1970s through the work of American artist and architect Gordon Matta- Clark [35], who realized the possibility of turning abandoned buildings to art installations and reinvigorate an energy in their surrounding urban space. His work emerged at the hype of youth activism, civil rights movements, and community participation that grew in defiance of architectural modernism, and was framed as *Anarchitecture*, a term coming from anarchism and anti-authoritarian architecture. These concepts gained a wide-spread popularity through the practices and writings of Jaime Lerner, previous mayor of Curitiba in Brazil, who turned them into effective practice [36]. The two famous acupuncture projects of Lerner involved changing the mentality of people for redressing the amount of pollution in the bays by directly engaging with the fishermen than a techno-scientific and engineering intervention, and the second was the Bus Rapid Transit system (BRT). These represented two different approaches and scales of intervention. In 2010, the Museum of Modern Art (MOMA) created a famous exhibition *Small Scale, Big Change: New Architectures of Social Engagement*. It showed case examples from Burkina Faso, Chile, Caracas and San Ysidro, California at the borders with Mexico [37]. These included multiple examples of architectures from primary school, half-empty housing to community-kitchens and mixed-use slits of land parceling. Urban acupuncture can be hyper-local interventions [38] and simply waste management in informality [39] for urban safety. Acupuncture can also be small-scale products and mobile apps what they call “little development devices” and “iShack agents” that boost social entrepreneurship in under-privileged urban settings using solar technology and “off the grid” technologies [40].

The qualification of most practices of “urban acupuncture” focus on space or products; they are deliberate designs with a prescribed challenge set in the mind of the activist beforehand. To evaluate their performance, further research, follow up and ethnographic analysis is need to test their acclaimed goals with time. There is a critique of the efficacy of such interventions and their complicity in normalizing the problematics of neoliberal city, by achieving quick gains without structural change and transformation. They are temporal solutions with a “calming down effect” acting as pain killers, momentarily diffusing the problem through a makeshift alternative [41]. They, however, distract attention from the main inequalities and serious issues. What acupuncture share with

modernism is its craving for protagonist, the heroic figure and the brilliant solution, the champion idea. If acupuncture aspires for placemaking, then it weathers down, what about the possibilities of an afterlife and place(re)making.

Urban acupuncture often addresses tangible dimensions such as social and physical ones. In this Cairo case, health - be it mental or physical- is presented through two potentials for reusing acupunctures at the time of the pandemic: Babaji yoga in al-Azhar Park [42], and the transformed *Sekketak Khadra* (meaning: your green way) outdoor sports installations and bike racks by the Merryland Park [43]. Those fragments brought people together, and as such, developed an afterlife for the underutilized infrastructure. Acupuncture as healing process impacts the body with the urge to develop a trickle-down effect with a larger hope for change.

Yoga Awakening

Al-Azhar Park is located in the eastern part of Historic Cairo near Darb Al-Ahmar with an area of 65 acres (See Figure II). At the heart of Historic Cairo, Al-Azhar Park's location was an accumulation of dust and rubble [44]; a collection of wars, fires, and waste piling up to a 45 m height dump for about 500 years [45]. In 1984, the Agha Khan planned to transform the wasteland to a park that serves the surrounding residents. The implementation of Al-Azhar Park started in 1997, completed in 2004, and opened for visitors in 2005 [46]. The Aga Khan Trust for Culture (AKTC) funded Al-Azhar Park with an amount of \$30 million. As the project's initiator and funding entity, the AKTC collaborated with Cairo governorate on a private-public partnership to manage and maintain the park. The project's landscape planner was "Sites International", while "Sasaki Consultants" cooperated with them starting from 1994. Every year, around 2-million people visit Al-Azhar park [47], of diverse socio-economic backgrounds.

The project aimed at adding "a green heart to Cairo" [48] by creating Al-Azhar Park as a public open space for the surrounding neighborhood; where the park encouraged further developments for the community (e.g. heritage, economic and housing) [49]. The park's components include a landscape of green cover, water fountains, lake, a playground, two lavish restaurants, an amphitheater, and the Historic Ayubid Wall area that has an entrance to the community of Darb Al-Ahmar. Placing the green spaces was strategic as it creates a panoramic alignment with Cairo's historic minarets and a vista directed to the Citadel complex.



Figure II Al-Azhar Park [50]

In the beginning of 2020, COVID-19 caused all public facilities to close, including public parks, hence, including al- Azhar park; which announced its closing till the 15th of June, 2020 [51]. It opened again for its visitors after six months [52]. When COVID-19 lockdown was lifted, safety procedures and conditions were announced by the Egyptian Prime Minister Dr. Moustafa Madbouly, which was applied to Al-Azhar Park accordingly. Its visiting hours, number of visitors and facilities regulations followed the national procedures [53].

Initiatives like the *Yoga Babaji* appeared, proclaiming those public spaces in an innovative manner before and after COVID-19 lockdown. Its founder is Ahmed El-Fouly, who graduated in 2010 from the Faculty of Urban and Regional Planning at Cairo University, and then became a professional yoga instructor in 2016. After a journey of self-discovery in India that lasted over two years, Ahmed returned to Egypt creating *Yoga Babaji Initiative* [54]. Throughout the years from 2010 to 2016, besides urban planning, Ahmed learned anthropology, sociology and psychology. He kept practicing yoga for mediation at multiple schools across India embracing the culture of caring, what Jaime Lerner defined as “urban kindness.” One of the significant practices of “karma yoga” in India is the provision of residency and meditation for free on the condition of giving back to the people and place. The yoga practice of *giving back* established a culture of immaterial caring, that was based on giving back to the best of one’s ability and not in return for money or commodity. Bonding with people, acquaintances and strangers, was part of nourishing the soul.

When Ahmed returned to Egypt in 2016, there were only 2 yoga centers and multiple initiatives. Ahmed embraced “karma yoga” and “urban kindness,” and in 2017 he began his first attempt to publicly engage in a yoga practice at an open space in Azhar Park on Friday mornings. He started the yoga public sessions every month. People used to come from afar, a yogi student came all the way from Menoufia Governorate about 95 kilometers, almost 2 hours away. The yoga sessions were for free with no extra ticket and al-Azhar Park did not intervene except for professional photography or journalism [55].

In 2017, *Babaji* started with 3 participants then increased to 15 participants from 2017 to 2018, and sometimes reaching to about 25 participants. At the outbreak of COVID-19, Ahmed was at Nepal, but he managed to return to Cairo in December 2020 and resumed the *Babaji* sessions with about 15 participants at Azhar Park (See Figure III); wearing masks for entrance and keeping social distancing as abided by the park regulations. Attendees age group varied, mostly mothers with their children. The relaxing atmosphere of bonding, especially after the yoga session helped everyone to de-stress. The female attendance was always higher than males. In extended discussions with two yoga instructors: Aya Ghazi & Rania Elmaghraby [56,57] and content analysis of yoga platforms on social media, it was concluded that male participation in is generally lower. Seemingly, yoga is stigmatized as a female practice under the discourse of feminist empowerment, whereas attending the gym is about masculinity and body strength.



Figure III *Yoga Babaji* in al-Azhar Park after lifting up COVID-19 lockdown [58]

Yoga Babaji bridges the gap between society and space through interweaving an immaterial relationship of kindness and highlight the wider important role of Egyptian youth in making change in our urban setting. The subtle practices of *mental health* tackles a growing stressful city. A healthy city cannot be approached in a top-down approach by abstract regulations and law enforcement decisions. Mandating wearing masks is a positive decision, but we need to move beyond such steps to tackle citizens’ mental health. With the limitation of green spaces in proportion to the growing population of districts, it is worth supporting and collaborating with grassroots initiatives of yoga and beyond towards a post-pandemic city, one that is concerned with the human health and soul flourishing. It requires a grounded effort of collaboration to support and empower those initiatives in a sustainable programmatic and systematic manner beyond a single event or a temporary boost of support.

Yoga Babaji is one of many grassroots practices of growing over the radar in Cairo, and there are plenty of them that arose as a post-corona response. They help in bringing people together, creating bonds between strangers and connecting them to their soul, place and the surrounding environment. Here, the paper addresses *Babaji yoga & Sekketak Khadra* as non-profit initiatives in outdoor settings. Supporting such initiatives economically to become a sustainable practice of *urban kindness* is another significant issue, how to become a business model towards urban kindness and not to slip into the fault lines of greedy fetich capitalist model of profit making. Again, the instant success of *Babaji* was driven by its choice selection of space, bringing people together across age, gender, and social class, with a sense of *giving back* without linking it to material gains.

Outdoor sports installation

Located in the affluent neighborhood of Heliopolis developed around circa 1902, Merryland Park covers an area of 50 acres, that used to be a horse racecourse, and is enlisted as a heritage site (See Figure IV) [59]. During Nasser’s rule, horse gambling was banned in the 60s, so architect Sayed Karim revamped Merryland, and after the 1973 war, Anwar Sadat adopted a development policy turning Merryland to a modern outing for the upper middle-class. During Hosni Mubarak’s era of privatization, in 1998, the park became managed by a private developer with the aim of rehabilitating its deteriorated condition. The park’s design followed recreational open and public spaces European scheme at the time of its establishment, given the increase in foreign residents [60].

The 2010 re-development proposal aimed at creating a park for the different social classes and different ages, solving the physical and social segregation issues, resolving the traffic problems created by the park at the neighborhood level and adding cycling infrastructure [61]. Its design was proposed to revive its 60s style; where the built-up area decreases to reach 10% of the park’s area, in addition to the old casino and the artificial lakes’ development, accordingly. Heliopolis Company and Cairo Governorate were not able to implement this re-development as planned due to the 2011 revolution, and was put on hold. In few years, the park’s southern section underwent renovation and was re- opened for the public in 2018 [62].



Figure IV Merryland Park, Heliopolis, Cairo [63]

In 2016, *Nahdet El-Mahrousa* NGO started *Sekketak Khadra* initiative, implementing bike racks in Downtown Cairo and Heliopolis, selecting spots where cycling rates are high [64]. With the support of the Danish Embassy, the Cairo Governorate and the UN Habitat, they aim at promoting cycling. They installed 100 bike racks with a fund of 200,000 EGP – about 12,500 USD. The Merryland Park’s station was one of the stations they added outdoor sports installation in addition to the racks (See Figure V).

Due to gyms shut down during the pandemic lockdown [65], people resorted to outdoor exercising. Heliopolis residents and people who jog in and around Merryland found a good and safe opportunity in *Sekketak Khadra*’s sports installation. Moreover, they started using the bike racks as part of their sports equipment and parked their bikes on trees and light poles right next to it (because the parking sign plates were stolen, so people did not understand its purpose and thought it was part of the sports installations and used them accordingly). This social adaptation to this spot is interesting because it additionally grew as a social node for safe-hangout during the pandemic, for instance, the space became a popular youth spot for skateboarding and more [66].



Figure V Sekketak Khadra's station at Merryland Park, Heliopolis, Cairo [67]

DISCUSSION

The question of addressing mental health in Cairo's spaces may sound awkward with the increased rates of poverty, pollution, social segregation, physical deterioration and underdeveloped health care facilities throughout Egypt, especially its rural hinterlands. But such problems do not negate the need to engage with the city's urban stress and the mediums for developing its mental health resilience in parallel. Learning from the experiments of urban activists such as the ones presented in this paper is quintessential. The objective is to adopt a serious agenda through spatial programs and retooling existing/underutilized infrastructure for urban healing and that hopefully a trickle-down effect in the different domains of city's malfunctional deficiencies. The urban strategy of intervention would be the surgical re-making of our places for all sorts of multiple events and social-health programs.

From the research investigation, before and during the pandemic, the active engagement of the parks' management with Cairo's citizens for the two cases explored in the paper were absent. Ideas and interventions for mental health often come from outside the park's management and city municipality. In the recent decade, the methodology of enhancing the built environment through urban acupuncture has gained wide attention amongst activists and grassroots movement to remedy the increasing political, economic, social and environmental deviations and injustices. They work through a tactical assertion of functions, installations, spaces and buildings in a well-selected urban spot to catalyze activities with the hope of triggering a chain reaction at a wider scale. Acupunctures may involve the recycling, upcycling, or the complete makeover of underutilized public spaces, or may result in rapid makeshift new architectures. They vary in 1) planning, 2) scale, 3) visibility, 4) effect, 5) funding, 6) governance and management. At the end what persists and continues to flourish are the acupunctures that involve people's needs and engage the community in the process of making.

The case of *Yoga Babaji* and similar yoga activities in al-Azhar Park, Merryland Park, Golf and Dog Park, and many more that we discovered through our semi-structured interviews, reveal a modality of "spontaneous acupunctures" [68,69,70]. A modality of open and flexible appropriation, light and rapid programs addressing immaterial issues for the soul, reminding people of their sanity and mental health. Those are activists who have been realizing a loss of soul connection in the city accompanied with increasing levels of stress. Those activities have grown over the years with an estimate of 200 yoga instructors in 2020, when there were about three yoga instructors before 2015 [71]. Their experiences of yoga classes in public parks inform us that it started with more female participants and currently the gender-based perception is changing with more male participants. At parks such as Merryland and Family Park, yoga instructors do not have enough room for meditation, given its loud events. On the other hand, a park like Golf and Dog Park in Nasr City presents a relaxing -and affordable- option for their practice (See Figure VI). In the researchers' opinion, its invisibility and insignificance for Cairo Governorate allows some leeway, flexibility and open-ended possibilities for people. It is a small green place remade "anew", simply through acknowledging people as "citizens".



Figure V Aya Ghazi's yoga class in Golf & Dog Park, Nasr City, Cairo [72]

As observed, the example of *Sekketak Khadra* offers an insight to an imposition of a planned acupuncture for the sake of creating a cycling boom without realizing extra dimensions such as vandalism. Nonetheless, the presence of the sports installation next to the bike racks allowed for an *unplanned* remaking of the place to become a social node during the pandemic; catalyzing a community of sorts, but not as planned and for the intended users.

What is significant here is the need to generate un-rigid plans, structures and management for people to unleash their energies for their mental and physical health. The present of arts installations, flexible street furniture, playful artifacts for the public energize people and make them connected to place and society. The emergence of yoga activists that has grown from unnoticed to the public realm is one example of how it is important to observe the changing patterns of how we need to re-manage and govern our public greenery, but also the need to incorporate mental health and well-being, according to people needs – and not what architects, planners, the public sector, and funding agencies assumptions and own goals.

CONCLUSION

The paper explains two modalities of urban acupunctures that grew from (un)planning, yoga practice and outdoor sport installations. It hypothesized a directly proportional connection between COVID-19 and those practices, in terms of needs increase; which this study proved partly correct. Our findings proved that yoga practices were more outdoor oriented before the pandemic, and returned as popular after it, with changes in gender diversity [73]. *Sekketak Khadra's* Merryland station was utilized by the community in their own manner during and after the lockdown, resulting in a social spot as much as an exercising one.

Thus, this research highlights the importance of re-making Cairo's green parks as places of healing and urban acupunctures to accommodate the growing global attention of WHO, NCDs, SDGs, and the UN-Habitat. It begs the question of: How can the urban majority of Cairo-citizens, destress? what are the lessons learned for architects, urbanists and landscape architects? How can "we" integrate a healthy and mindful design in an overly-dense city when functional green spaces are a scarcity and operate in a controlling manner? How can a mentally health city be transformed from below? What are the efforts of urban youth activists working on such problem when such agenda of mental health and well-being is still absent in many Cairo's municipalities?

The loss of jobs, economic instability, social tensions and domestic violence that grew with the lockdown in a massive dense city with few accessible open green spaces in a city like Cairo cannot be dismissed and ignored by urban designers, planners and municipalities. The rising number of male participants in yoga practice and other social trends reveal the need to incorporate such activities than dismissing them as anomalies. The yoga gatherings represent a mode of acupuncture that is unanticipated by urban experts yet surprisingly effective offering inspirations to learn from. *Sekketak Khadra's* case represents an example of an urban acupuncture that people turned around and reused in a successful manner.

These spontaneous acupunctures grew out of the (un)-planning of experts to anticipate the transformative nature of people's needs, emergency crisis and mental health requirements in planning. The pandemic has exposed the incapacity of some of Cairo's existing parks to adapt the changing needs of mental health and well-being. It is not too late to rethink and remake parks to be open for people in the true sense of openness and empowerment, to let go of their control, to engage and support Cairo residents' well-being.

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EVALUATING THE ECONOMIC FEASIBILITY OF SUSTAINABLE HOUSING PROJECTS IN EGYPT; A CASE STUDY

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ABSTRACT

In recent decades, the world is suffering from resources depletion, heavy construction industry, this makes it imperative to increase efforts towards sustainable construction, where it can achieve an economic feasibility for many countries. This paper aims to undergo Life Cycle Cost Analysis (LCCA) of a sustainable building as an initial step towards evaluating its feasibility in Egypt, as feasibility is a long and complex process, this paper constitutes the first step. This research is based on a case study for sustainable residential project in Egypt. Data were collected, life cycle costs were analyzed, payback period and financial savings were determined. Despite the high initial cost of sustainable housing projects, the results proved that the costs of the operation and maintenance phases were 34% lower than conventional housing, and were able to cover the initial cost within a reasonable period of time, according to the inflation rate for the year 2020. As the (LCCA) has proven the cost-effectiveness of sustainable residential buildings over the life of the project, more studies are needed that assess not only the economic feasibility, but the environmental as well.

KEYWORDS

Economic feasibility, Sustainable building, Residential, Life cycle cost Analysis (LCCA)

INTRODUCTION

The world is currently experiencing serious economic problems, with challenges such as the heavy construction industry, resource depletion, high carbon emissions, global warming (1). Their effects on the local and international economy are severe. Thus, it is imperative that the construction industry be more concerned with natural resources, energy consumption and overall reduced environmental impact, which requires more thinking and increase efforts towards sustainable building.

The housing sector is a major consumer of energy and a contributor to global warming. In Europe, heating and hot water for residential buildings consume about 40% of total energy consumption and 30% of carbon gas emissions (3). Whereas sustainable housing is “Housing that meets the needs and requirements of the present generation, without compromising the ability of future generations, to meet their housing needs and demands” (4). In order to design a sustainable residential building, residents’ comfort and expectations, environmental impacts and economic stresses must be considered (5).

In Egypt, the population is increasing by 2.5 percent annually, according to the Central Agency for Public Mobilization and Statistics, and is expected to reach 151 million people by 2050, with a population of 102 million in 2020, Thus, increasing the rate of construction of housing units achieved in urban areas, and the total housing investments of the public and private sectors, accordingly Central Agency for Mobilization and Statistics (6). Despite the state’s keenness to achieve the appropriate quality for these projects, most of their designs lack the principles and objectives of sustainable housing (7).

Conventional residential buildings have a minimum initial cost, and a high operating and maintenance cost. as well as the total life cycle cost throughout the life cycle of the building. Its environmental impact is also high due to its high energy consumption during construction and operation. On the other hand, the literature confirms that sustainable residential construction has lower energy consumption and lower environmental impact throughout the life cycle of the building (8). For the fact that resources are used wisely to create higher quality, healthier and energy efficient housing units. Despite these benefits, the high initial cost is the main obstacle to sustainable buildings (3). Sustainable housing practices still face many barriers. Therefore, this research aims to assess the economic feasibility of sustainable housing projects in Egypt.

The construction of a well-designed sustainable residential building requires more efforts; To balance the primary goals of social, environmental and economic sustainability as well as consideration of structural and aesthetic criteria. This requires investigation from the economic side of sustainable housing projects in Egypt, which is one of the three pillars of sustainability.

Debate is still going on as to whether the operational savings of sustainable buildings can recover the initial construction cost (9). Therefore, this paper is subject to a Life Cycle Cost Analysis (LCCA) for a sustainable building. As an initial step towards assessing its feasibility, by conducting a life cycle cost analysis of a sustainable housing project in Egypt to clarify the payback period, as well as the amount of financial savings; To be used by the real estate developer, homeowners and engineers as inputs to assist them in the decision making or evaluation process, to select the best sustainable residential building that meets the minimum total life cycle cost (LCC).

Where sustainable residential construction is no longer a luxury. While it is a goal and a process; It is important to see it as a process. Because the success of this process does not only lead to building with green materials only, while it results in a sustainable residential building. That combines the durability of materials, increased efficiency, savings and the ability to absorb economic, environmental and social shocks.

MATERIALS AND METHODS

This study depends for Life cycle cost Analysis (LCCA); In order to evaluate the feasibility of sustainable building projects. Data was collected for the (LCC) of the conventional residential project from previous literature in this field, then choosing a sustainable housing project in Egypt as a case study. Their life cycle costs are analyzed over a 30-year lifespan. In order to determine the amount of financial savings and the time period for recovery; The project life cycle costs of the case study are assumed if they are non- sustainable. The Net Present Value (NPV) of all costs of the project life cycle elements is calculated by applying the (NPV) method for them; To take into account the time value of money over a period of 30 years (10). The (NPV) method provides evaluation and comparison for projects that occur in different time periods, as it put into calculation the time value of monetary and produces realistic results. By converting all cash flows (costs) to a single amount equivalent to their time value at the beginning of the analysis period, before they are combined to the project’s (LCC) account. Discount and

inflation rates are determined according to the Central Bank of Egypt and the Central Agency for Mobilization and Statistics. The average monthly costs of electricity and water consumption for conventional luxury housing units are calculated, according to the statistics of the holding companies for both electricity and water.

Method of Data Collection:

Data on life-cycle costing methods for conventional residential construction were collected from the previous literature, relevant to this field. Energy and water prices for the average consumption of luxury housing units in Egypt were obtained through the Electricity and Water Holding Companies <http://www.eehc.gov.eg/>, <https://www.hcww.com.eg/>. Inflation and interest rates in Egypt for 2020 were also obtained from the Central Agency for Mobilization and Statistics and the Central Bank of Egypt. Data was collected for the sustainable housing project (case study) through interviews with those responsible for the project implementation process, in the company that establishes the project.

Description of the Case Study Project:

The case study is chosen based on the fact that it is one of the first experiences of sustainable housing projects in Egypt. The project (Castle Landmark) is located in the seventh residential district, R7, Block A1 in the New Administrative Capital, east of Cairo, as shown in Figure 1. Data on the case study is collected by the company, that owns the project (Castle Development). The Life Cycle Cost Analysis (LCCA) is being studied and analyzed for the first and second phases of the project, as it is still under construction, which helps in the assessment process, about whether the operational savings for sustainable buildings can recover the initial construction cost, as well as to determine the payback period, and the amount of financial savings; to encourage other companies and real estate developers on building sustainable housing projects, not only for their environmental feasibility, but also for their economic feasibility.

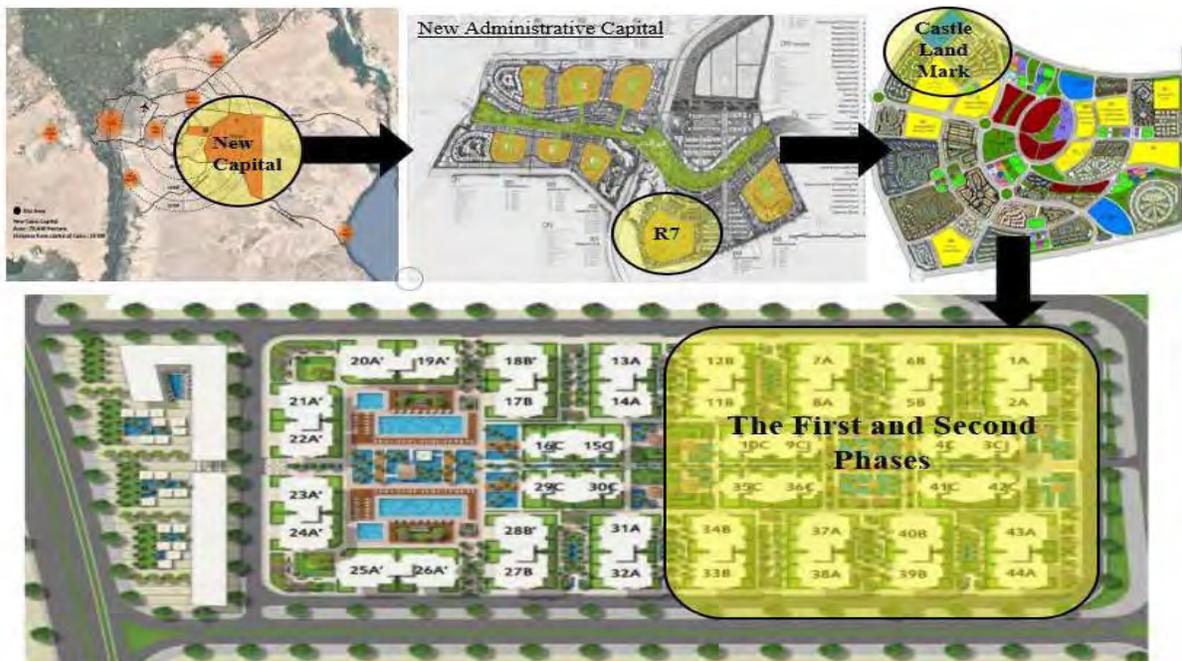


Figure 1. Location and Layout of case study project (Castle Land Mark) in Egypt

The two phases consist of 24 residential buildings. The apartment consists of a ground floor and 7 repeated floors. The figure 2 shows the site, construction status of the project and its form after implementation. The ground floor of each building consists of 5 units, and the repeated floors consist of 6 units for each floor, with a total of 1128 housing units. The project relies in 70% of its activities on the use of solar energy, as it provides innovative solutions to manage the infrastructure components within the project, rationalize energy consumption, and provide safe, efficient and environmentally friendly products, including energy generation through the use of solar energy, heating and water systems.



Figure 2. The case study project (Castle Land Mark) in Egypt

Analysis of the Case Study Project:

The data collected consists of the initial project cost, annual project operation and maintenance cost estimate, annual non-recurring costs, replacement cost and salvage value. The age of the building is considered to be 30 years. This is to analyze life cycle costs (LCC). All the above costs, which include (materials, labor, fixtures, etc.) are analyzed and estimated if the building is not sustainable, and then analyzed and estimated again in the same method if it is a sustainable building.

Determination the Payback Period:

Payback period is calculated as the year in which financial savings exceed the present value of the cumulative cost of routine maintenance, replacement and energy consumption over the specified life (30 years) in constant pounds, often represented as future annual costs. Financial savings are determined by appropriately deducting the costs of each stage from each other for each year for both cases for 30 years. The NPV method is also applied to estimate savings in event of the building's sustainability and then adding the initial cost of the project on the base date. In order to determine the amount of expected financial savings. Then the values of financial savings are graphically represented over the study period (30 years), in order to determine the period of time or time in which the initial cost of the project is covered. All calculations are done using MS Office Excel.

Analysis of Estimating the Costs of the Economic Life Cycle:

Conventional buildings consume about 40% of global energy, 40% of other natural resources, 25% of global water, and emit nearly a third of carbon emissions. While sustainable buildings have 19% lower total operating costs, 25% Less energy, and 36% less carbon emissions (11).

This method is used for evaluation, control and management of investment projects. Where it has the possibility to show all costs and revenues of investment projects in a concrete form, including all elements at the time of their request. The (LCC) approach takes into account all costs, and revenues associated with an asset over its economic life cycle. Important inputs (such as costs incurred over the life cycle of the investment being analyzed) are collected through the (LCC). The life cycle cost is the total cost of ownership, operation, maintenance and demolition of the building during its life span. The (LCCA) depends on four elements (12). which are the costs related to:

- A - the initial cost/investment cost.
- B - the cost of operation and maintenance.
- C - the cost of disposal.
- D - the life of the facility.

In life cycle costing, future costs, such as operating energy costs and maintenance and replacement costs associated with an item, must be discounted to their present values before being added to the item's acquisition or purchase cost (13). The (LCC) for project in this paper are calculated through the sum of the initial cost, operational energy costs, maintenance and replacement costs and then deducting the salvage value (14). The life cycle can be formulated as:

$$\text{Life Cycle Costing (LCC)} = \text{I} + \text{E} + \text{M} + \text{R} - \text{S} \quad (\text{Eq. 1})$$

Where, **I**= Initial cost.

E = Present value of energy costs.

M = Present value of annually recurring maintenance cost.

R = Present value of non-annually recurring replacement cost.

S = Present resale value or residual value or salvage value.

Economic Feasibility (Net Present Value Method):

Net Present Value (NPV) is one of the best systems for evaluating construction related cash flows. It is widely known. It is used to properly evaluate future cash flows. The net present value is defined as the sum of money that is required to be invested today, to meet all future financial needs throughout the investment period (10). The name present value of costs refers to the equivalent value of time. The discount rate is the interest rate required to convert the value of future expenses to their present at the base date. Determining the appropriate discount rate is the basis for assessing future cash flows correctly, taking into account the time value of financial and the rate of inflation. The time value of financial should be discounted to its current value by proper equations. All apparent variables that affect cash flow are taken into consideration. The (NPV) equation is below (10):

$$\text{NPV} = \sum_{t=0}^T \frac{C_n}{(1+ds)^n} \quad (\text{Eq. 2})$$

Where, **NPV** = Net present value

C_n = Cost in the future year *n*

ds = discount rate

n = number of years in the future

The discount rate can be formulated as: $(1+ds) = \frac{(1+\text{interest rate})}{(1+\text{inflation rate})}$ (Eq. 3)

This method provides an assessment and comparison of the cash flows, that are spent over time for investment projects. It is also effective for evaluating and comparing project expenditures at the time of sudden economic crises.

ANALYSIS OF THE CASE STUDY:

Economic evaluation of the (LCC) of a residential building (case study) requires identification of the costs necessary for each stage of the life cycle. Building (LCC) includes the initial cost, which is an essential part of the entire (LCC), as it is the construction costs, engineering fees and office costs. It also includes operating costs that represent utility costs such as costs for fuel, electricity and water (15). It also includes maintenance costs, and the cost of major repair or replacement. In addition to calculating salvage value, salvage value is defined as the current resale value (14), the value that can be recovered at the end of the study period, or the residual value.

Initial Cost:

The initial cost was obtained by collecting information on the initial cost of building the sustainable housing project from the developer. Which includes the price of the land, site works, foundations, roofs, external walls, interior finishes, electrical and mechanical costs, prices (materials and labor) necessary to achieve sustainability criteria for the project, such as in addition to the costs of project registration fees in the World Green Building Council on LEED certification.

Operation Energy Costs:

Several factors that affect the energy consumption of residential buildings are the building envelope, its configuration, occupancy rates, weather conditions and behavior of its occupants, and the efficiency of heating and cooling equipment. Since it is not easy to model these costs, though, for the purpose of evaluating the life cycle cost of apartment buildings, the operating and energy cost is calculated by converting all the monthly expenses such as electricity charges, water charges, detergents, guards, etc. To annual expenses. This is done by assuming that the project is not sustainable (conventional), and accordingly, the average monthly energy consumption costs are determined, and this is done through the average consumption segments according to the statistics of the holding companies for both electricity and water for luxury housing units. It is estimated annually over the life of the project (30 years), taking into account the price increase by 10% for each year. The net present value (NPV) is calculated at a discount rate of 1.05% for 30 years. Operating energy costs can be formulated as follows:

$$\text{Operating energy costs (annually)} = \text{ACE/ month} * \text{APE/month} * \text{NU} * \mathbf{12} \quad (\text{Eq. 4})$$

Where, ACE = The average consumption of a residential unit (luxury) for electricity and water per month, according to the statistics of the holding companies for electricity and water.

APE = The average price of KW electricity and M³ water per month, according to the prices of the (**luxury**) housing segment according to the electricity and water holding companies, NU = The number of units, **12** = The number of months in the year

LEED residential buildings consume on average 30% less energy than conventional residential buildings on code (16). The project also provides good performance for water consumption, as it is equipped with water-saving installations throughout, in addition to a drainage pipe system connected to an on-site tank to capture rainwater for landscaping, which leads to a decrease in the total internal and external water consumption by 57%, compared to the consumption of residential projects conventional water. The annual operating energy costs of the sustainable residential buildings were estimated for the case study project, in the same method, at a discount rate of 1.05%, for 30 years.

Replacement and Maintenance Costs:

Residential buildings require many forms of routine maintenance, and owners sometimes need to repair or improve the quality of their exterior finishes. This is reflected in the utility bills paid by residents. Replacement costs for components such as the well, elevators, electrical and plumbing are calculated on the basis of the initial construction cost. Where routine maintenance and replacement costs are assumed to be 0.5% of the initial costs for each year. Replacement costs for components such as the well, elevators, electrical and plumbing are calculated on the basis of the initial construction cost. Well, lifts, electrical and plumbing must be replaced after 10, 20, 20 and 40 years respectively, in addition to non-annual recurring cost such as staining done after every 10 years (14), taking into account the price increase by 10% for each year. Average replacement cost is assumed to decrease maintenance for sustainable LEED residential buildings; As a result of the project's lower operational energy consumption, it is 21% (17) lower than that of maintenance and replacement costs for conventional residential buildings. Accordingly, LEED-certified replacement and maintenance costs are determined by regard to the percentage reduction in cost compared to the maintenance and replacement costs of conventional buildings, which were using the NPV method, and a discount rate of 1.05% at the age of 30 years.

Salvage Value:

The salvage value is calculated as 10% of the initial cost of the residential building from the total initial construction cost (14).

FINANCIAL SAVINGS AND PAYBACK PERIOD

Financial savings for sustainable residential buildings for 30 year was estimated. by deducting the costs of operating energy costs, maintenance and replacement costs, which are analyzed for sustainable residential buildings for each year from the operating energy costs, maintenance and replacement costs, which are compared for conventional residential buildings from pervious literatures. This is in order to determine the amount of expected financial savings for sustainable residential buildings. The NPV method was applied; To determine the savings in both cases before discounting them to each other, and then adding the initial cost of the sustainable buildings on the base date and salvage value. It can be formulated as follows:

$$\text{Financial savings} = [(\text{NPV}(\text{E}+\text{M}+\text{R})) + \text{I}+\text{S}] \quad (\text{Eq. 5})$$

Where the financial savings for sustainable residential buildings for 30 years, at a discount rate of 1.05% was **3,361,159,605 EGP**. Based on the estimated values of financial savings over the age of 30 years, the payback period was determined. The payback period is calculated as the year in which the financial savings exceed the present value of the cumulative cost of routine maintenance, replacement and energy consumption over the specified life (30 years), in constant pounds, graphically represented at They are future annual costs as shown in Figure 3.

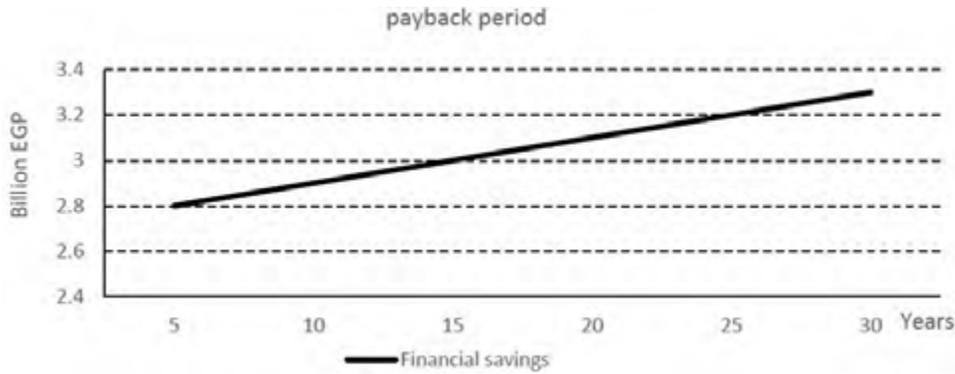


Figure 1. payback period for sustainable residential buildings

RESULTS

The results show the values which was obtain for the initial cost, operating energy costs, replacement costs (non-annual), routine maintenance (annual) and salvage value, for 30 years of the building’s life, at a discount rate of 1.05%. Total (LCC) is calculated by summing all these costs and deducting the salvage value. The (LCC) for sustainable residential buildings is obtained by the NPV method in the amount of **1,872,866,864 EGP**. The result of (LCCA) of sustainable residential buildings in Egypt by NPV method is presented in Table 1.

Table 1. Life cycle cost of sustainable residential building for 30 years at 1.05% discount rate.

| Description | NPV method (cost in EGP) |
|--------------------------------------|--------------------------|
| • Initial cost | 2,500,000,000 |
| • Operation energy costs | 426,368,367 |
| • Maintenance cost (annual) | 128,639,891 |
| • Replacement (Non-annual) | 224,142,750 |
| • Salvage value: | -250,000,000 |
| • Total Life Cycle Cost (LCC) | 1,872,866,864 |

The results indicated that sustainable residential buildings achieve financial savings in the long run. Where it was for 30 years at a discount rate of 1.05% **3,361,159,605 EGP**. The payback period was also found when the amount of financial savings crossed the fifth year of the 30 years study period, and became covering the initial cost at the base date. The NPV method has the advantage that it put into calculation the time value of monetary, cost of capital and risks such as sudden economic crises. It gives realism to the results to make predictions about the future. Therefore, this method is effective in the financial management of future costs for evaluating the feasibility of residential building. The net present value (NPV) of profitability gives risk a high priority to projects.

DISCUSSIONS

The initial cost of the project made it possible to infer the costs of sustainable measures, in the 30-year period of the study. Although sustainable housing projects required a higher initial investment cost. In economic sides, at the end of the thirty years, sustainable measures made it possible to achieve an economy of about **3,361,159,605 EGP**. This economy is due to lower operating costs (electricity and water). This study encountered difficulty when trying to calculate the net values of the financial benefits, achieved by some measures. Some difficulties have also arisen when anticipating some of the costs of routine maintenance and replacement, as well as operating costs. This study found financial savings accrued for all sustainable measures in the case study project as well as maintenance solutions, although this is not the most desirable method for performing this process. Other difficulties are found when trying to calculate the added value that these measures bring to the residential building, by improving the comfort and quality of the indoor environment, user satisfaction, etc. There are also other ongoing parallel positive effects that these measures bring, which are also difficult to measure, such as reducing carbon gases, by reducing fuel consumption, reduce waste, etc. This analysis is useful, as studying how parallel environmental and social impacts translate into economic values. It would be very useful, and help in calculating the true impact of the sustainability of residential buildings, through the life cycle. The sustainability innovations considered in the case study represent only a few of the innovations, or solutions that can be applied to sustainable residential construction. Where sustainable residential buildings consume operational energy by 30%. Compared to the energy consumption of conventional residential buildings. The reduction in operating energy consumption results in savings in energy consumption costs by 34% less than the energy consumption costs of conventional residential buildings. As a result of reducing energy consumption costs, and more reliance on clean energy, energy-saving equipment and installations, maintenance and replacement costs for sustainable residential buildings are reduced by 21% compared to maintenance and replacement costs for conventional residential buildings. Operation and maintenance costs were calculated for the case of the study, as well as in the case if it was conventional, for 30 years, according to the inflation rate for the year 2020. was found the operating and maintenance costs of conventional housing represent 41% of the total life cycle costs, while the operating and maintenance costs of sustainable housing represent 24% of the total life cycle costs for 30 years, as shown figure 4.

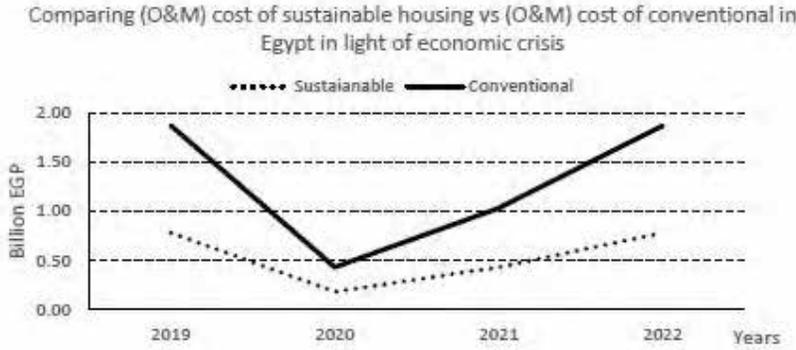
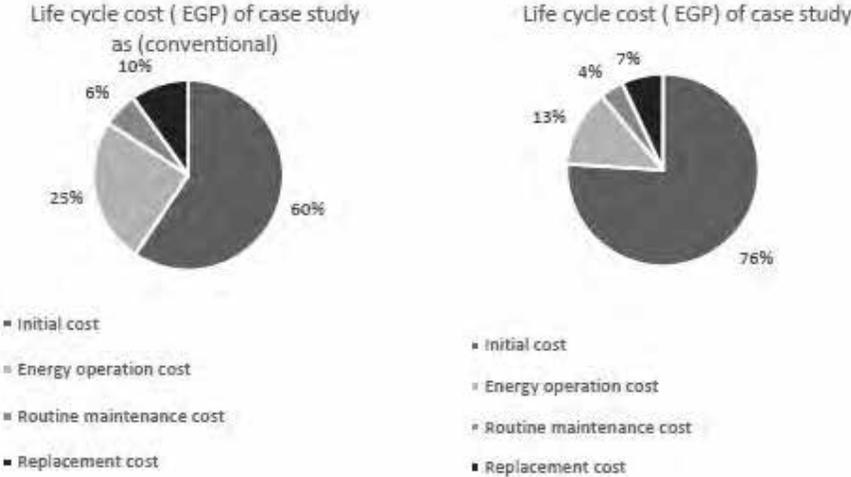


Figure 2. Economic feasibility of sustainable housing in light of economic crisis in Egypt

Also, Operation and maintenance costs were calculated for the case study, as well as in the case if it was conventional, over lifespan 30 years, according to the inflation rates of the last four years; To evaluate the economic feasibility in light of economic crisis. The results indicated that the average operating and maintenance costs of sustainable housing projects are 29% lower than the conventional over lifespan 30 years. Which means that sustainable housing projects are the most resilient in sudden economic crises, as shown figure 4.

CONCLUSIONS

The Economic challenges such as high inflation rate and overpopulation caused a recession in the Egyptian economy. Accordingly, it is imperative to increase thinking and efforts towards sustainable construction.

In particular, sustainable housing projects, where housing is one of the important fields, that can help achieve an economic return. The NPV method is effective in correct planning and financial management for costs and future residential building activities, and helps in maximizing asset values, though it is difficult to use. The feasibility is a long and complex process. The life cycle cost analysis (LCCA) methodology is useful and effective in identifying and calculating costs and savings for residential projects. The operation and maintenance phases are considered the most expensive during the life cycle of residential buildings. Sustainable residential buildings achieve long-term financial savings in the operation and maintenance phases, through their reduced consumption of energy and water, allowing the savings to cover the initial cost within a reasonable payback period of about five years, as shown by the results. Despite the discount rate of 1.05%, which was calculated according to interest rates and inflation for the year 2020.

sustainable residential buildings offer a number of economic or financial benefits, which relate to owners, tenants or developers as a result of savings in utility bills costs to users (through energy and water efficiency), increasing property value for developers, increasing occupancy rates. In addition to their environmental benefits and energy efficiency, conservation of natural resources. As well as its social benefits of being healthier and better suited to users' needs. Evaluating the investments needed for sustainable housing projects that enhance a building's performance over its lifecycle is a challenge for owners, developers and policy makers, when deciding on them; Due to their high initial cost, but they offer solutions and innovations that combine both material durability, maximizing efficiency and savings. Sustainable residential projects have economic feasibility high. Their helps push the Egyptian economy forward. So, studying and evaluating the economic feasibility is ongoing research, and the next step is to make an analogy between the case building, and other scenarios including the same building with non-sustainable (conventional) designs.

ACKNOWLEDGMENTS

This work was done with the assistance of (CASTLE DEVELOPMENT) for real estate development by providing data on the case of the study - sustainable housing, as it is the company that owns the project.

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REREADING CAIRO THROUGH NEIGHBOURING PATTERNS BETWEEN FORMAL AND INFORMAL AREAS, CASE STUDY: ARD AL-LEWAA AND EL- MOHANDESEEN

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ABSTRACT

Cairo is featured by its various and multiple urban patterns with different, similar, converging, and intersecting relationships resulting in different neighboring patterns. Despite frequent interventions to improve vehicular movement throughout the city, such projects have different impacts on the local scale inducing urban segregation/integration between different parts of the city, namely planned (formal) and unplanned (informal) areas. This research aims to study the different neighboring relationships between formal and informal, providing a subsequent new classification for unplanned areas. Additionally, the research investigates complexities related the integrated development approach as well as addressing mobility issues when dealing with unplanned areas and their relation to the rest of the city.

The research methodology is divided into two parts, first: through inductive and analytical approaches, relevant literature is reviewed to analyze the historical development of Cairo leading to the current status along with the previously established classifications of its urban areas. Additionally, maps are utilized to identify the different urban layers and understand spatial relationships and hence extract criteria for defining different neighboring patterns in Cairo. Second, through an empirical study, the research investigates “Ard Al-Lewaa”, an unplanned area and its relationship to the adjacent El-Mohandeseen planned area reflecting the juxtaposition of the two urban form and morphology in Cairo. The investigation delves into their development history, reciprocal urban influences as well as the condition and characteristics of the in-between spaces and connection elements. Through the analysis of previous development attempts that took place 2011/2012 within these spaces, the study highlights the problems arising from neglecting this neighboring relationship. The paper relies on geo-spatial analysis of Ard Al- Lewaa as a case study to showcase current gaps and issues of isolation, as the neighboring pattern.

The research concludes by defining a new classification for the neighboring patterns between planned and unplanned urbanism in Cairo. In addition, it highlights lessons and criteria for interventions within the spaces in-between Ard al-Lewaa and El-Mohandeseen areas and points out mobility and transportation systems as critical elements in enhancing their integration and inclusiveness.

KEYWORDS

INTRODUCTION:

Unplanned areas, or “*ashwa 'yat*” show more than one pattern, depending on the context of their origin (urban or agricultural), legal, and structural state. In the context of Cairo, slums and unplanned areas have different features compared to the rest of the city, despite their geographical integrity (8). Moreover, the rapidly growing population of urban areas, the dynamics of economy, social changes, as well as the scarcity of available formal housing, all together have intensified the urbanization process. This process, officially, takes place through the development of major road networks, meanwhile illegal urbanization usually takes place on the periphery (18).

There are different relationships that connect Cairo’s planned and unplanned urban areas. The adjacent model, is the most notable, where a planned and an unplanned area are adjacent in various ways, mostly common in city core rather than the peripheral new cities. This has become a contemporary model that differs from the classical model of proximity between historical Cairo and Khedival Cairo. In the classic model, historical Cairo was well recognized by community rules interfaced Khedival Cairo that was planned in a European style. In the current dichotomy, the opposite occurred where planned areas were already in place, followed by non-planned areas that were built according to local codes but not formally recognized.

Tracing the growth of Cairo’s urbanization reveals the political and social conditions in which the contemporary neighborhood model of Cairo was formed during the period in which the city witnessed its greatest expansion. Starting the mid-20th century, official subsidized housing was launched for lower- and middle-income social groups. However, by the end of the 60s, the state quickly retreated from providing this support because of the war conditions, which led to the need for a new type of housing that these social groups could afford. Consequently, the growth of the unplanned areas began until its growth spiked at the end of the seventies. This coincided with the launch of the new cities policy in the late seventies with the aim for partial control over the growth of the unplanned areas. In the nineties, the state adopted a security approach towards unplanned areas, which are difficult to penetrate and manage, considering them a threat to national security. Therefore, the government felt the need to dissect its urban fabric. In the first decade of the new millennium, unplanned areas became the dominant pattern of Cairo’s urbanization, and their problems exacerbated and affected the rest of the city’s urbanization at a time when new cities expanded a lot despite the low demand and their slow growth, compared to what was planned to accommodate the expected population (5).

Studying previous attempts and approaches, either by scholars or authorities, to understand and classify various urban patterns in Cairo is a starting point in this research. According to Sims (2013), Cairo consists of three cities in one city: the planned, unplanned and the new cities of the desert (20). His analysis relied on the temporal patterns, type of tenure, and urban development approach. Regarding classification of slums, according to the Informal Settlements Development Fund (ISDF), recently renamed into Urban Development Fund (UDF), they are divided into unplanned areas and unsafe areas. The UDF used the criteria of UN-Habitat for slum definition in analyzing and identifying 404 unsafe areas as unsafe areas (4, 8). The General Organization for Physical Planning (GOPP) on the other hand, classified informal areas into four types: building on privately owned agricultural lands, construction on state-owned land, deteriorated historical centers and finally urban pockets. Thus, GOPP established two basic criteria for defining informal areas: the legal status or type of tenure and the extent of deterioration (24). Legally, the “Unified Building Law ‘ No. 119 of 2008, classified informal areas in two main types: unplanned areas and redevelopment areas. This shows common criteria among different entities and scholars that defined informal areas/unplanned areas relying mainly on legality of land ownership and building permits, while unsafe areas are a subsector that suffer from extreme deterioration.

Within such complex phenomenon, this paper investigates new neighboring patterns within megacities of the global south, with an emphasis on the Greater Cairo Region. It identifies several reciprocal and segregated relationships with relevant challenges. The paper analyses the in between spaces that lie within the planned/ unplanned areas interface. It criticizes previous interventions within a case study in Ard Al- Lewaa in pursuit of a more responsive utilization of such asset towards a more inclusive city.

METHODOLOGY:

The paper used a threefold methodology to investigate the current juxtaposition between the planned and unplanned First, the paper analyzed urban patterns in the city and their classification through related literature. Second, surveys and mapping of new inputs that informally arise throughout the city was conducted including informal activities, interventions along mobility routes of corridors. Mapping also included different layers of juxtapositions using case studies such as: Ezbet Khairallah and Ard Al- Lewaa. In addition, mapping reciprocal relations was conducted through analyzing boundaries and borders, mobility, and movement routes and corridors, and waste management. Third, through the analysis of Ard Al-Lewaa as a case study, the researchers used an immersed actor method as being active members of the local initiatives that took place during the period that extended from 2015 to 2016. The researchers conducted a chronological study of interventions using mapping, photos, and video documentation.

LIMITATIONS:

The research focuses geographically on the Greater Cairo Region, as it is the largest urban complex in Egypt and includes a huge variety of juxtapositions between urban patterns. The first phase of the neighboring patterns was done between 2015 to 2016; relevant data availability is reflected in the analysis results.

INVESTIGATING NEIGHBOURING PATTERNS IN GREATER CAIRO REGION

Mapping Neighboring Patterns in Cairo between Formal and Informal Areas:

The researchers investigated patterns of neighboring between formal and informal areas in Cairo. Classifying urban patterns was firstly: based on their origins of growth (on agricultural or desert land), secondly on unplanned or unsafe according to ISDF mapping and classification. The researchers found that correlations between different urban patterns (planned and unplanned) happened in specific forms of juxtaposition which occurs in several areas. Correlations between areas as layers of reciprocal relationships address overlapping, contradictory and intersections between areas such as boundaries and borders, mobility and movement axes and garbage collection areas. shown as follows.

Boundaries and Borders

Analyzing administrative boundaries overlapping with urban patterns reveals how more than one urban pattern may come together within the same administrative boundaries as shown in fig 1. For example, some unplanned areas such as Imbaba include more than one form of urban patterns within its administrative borders including planned areas (10), sharing together the same services, despite the difference in density, as well as their population distribution. The Agouza district includes within its administrative boundary planned areas such as El-Mohandeseen and unplanned areas such as Mit Oqba, Al-Houtia and Ard Al-Lewaa However, the latter showed an example of frequent change in its administrative dependency. Ard Al-Lewaa has been part of al-Agouza district since 2009, previously, it was part of Kerdasa, a rural village at that time, then moved to be part of Bulak al-Dakroun district. This repeated change in both urban-rural nature and administrative dependency had impact on its rental laws. Currently, there are around 5000 inhabitants at risk of being evicted from their homes regarding current rental law and difference between urban and rural settings (15). Another example is the east Nasr City district that includes Ezbet Al-Haggana area, one of the largest unplanned areas adjacent to planned areas. Al-Zaytoun district combines three different urban patterns from unplanned and planned areas as well as areas from historical Cairo. Dar al-Salam district combines different informal patterns including unplanned areas on agricultural lands, others on desert and unsafe areas in addition to planned areas. Oppositely, “Izbat Khairallah”, for instance, is one of the unplanned areas, despite having clear spatial boundaries, it is distributed between more than one district administratively (21).

Regarding natural borders, the Nile River, and the eastern plateau, or Jabal Mokattam to the south of Jabal Tora, stood as an obstacle limiting urban growth to the east, and pushing the growth to the north and south. The Mokattam area was developed above this edge after paving the roads and improving its connection with the city. Other types of borders include industrial borders represented by railway which represent an obstacle separating communities on both sides, especially after the successive closure of surface crossings (*mazlakan*) and replacing them with pedestrian stairs and car bridges as shown in fig 2.

Mobility, Routes and Corridors:

Means of transportation such as minibuses are commonly used on the borders within unplanned areas or in the interface of unplanned areas and planned areas taking advantage of infrastructure in the planned areas. Means of transportation are compatible with the urban characteristics and the movement intensity in terms of supply and demand besides, the influence of the bad conditions of streets regarding width and accessibility. As streets in informal areas are narrow, and not paved, most people use tuk-tuks for shorter distances which are unlicensed and at many times operated by teenagers representing another informal feature (23). Tuk-tuk is banned in some new cities and replaced by van cars (9), revealing a contradictory situation of executives, where it is licensed in some districts and rejected elsewhere (3). Mapping buses routes in fig (3) showed how informal areas lack accessibility to public transportation. Many neighborhoods in these areas rely on mass transportation that are not served at all by public transportation and instead rely on privately owned and operated minibuses, tuk-tuks or riding in the back of pick-up trucks to the closest public transportation or minibus stop, lay in the formal side (23).

Routes and corridors: streets and highways intervene with informal areas either creating borders or cutting edges through patterns. The Ring Road, a commonly used highway, is used by both planned and unplanned areas. It was initially designed to achieve two main goals, firstly to remove traffic congestion outside the city center, and secondly to limit the growth of informal extensions forming a new border for the city. The intention was to make a clear demarcation to the boundaries of legal construction. Finally, the Ring Road enhances connectivity between the city core and the new cities in the desert (19). Surveying intervention along the Ring Road revealed intensity of informal interventions by unplanned communities that this highway penetrated, such as entrances, bridges, ramps, staircases near bus stops and car maintenance-related workshops (11).

Garbage Collection Areas:

Garbage collection and recycling areas are considered repulsive areas in Cairo, despite their important function and contribution in collecting Cairo's waste disposal. The map in fig 4 shows the distribution of the major areas specialized in distributing garbage, it is clear that they are all located in unplanned areas, which highlights one of the important relationships of these areas for planned areas in Greater Cairo Region.

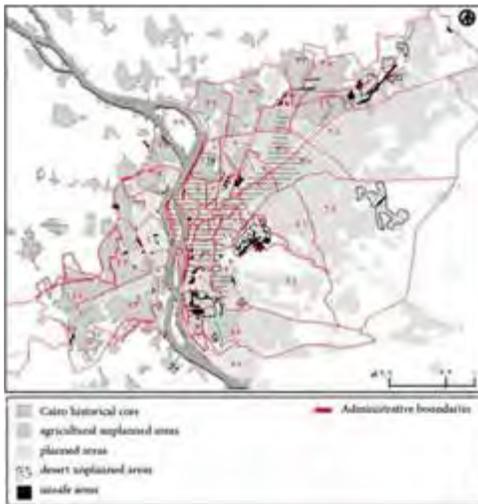


Fig 1. Administrative boundary (source: researchers)

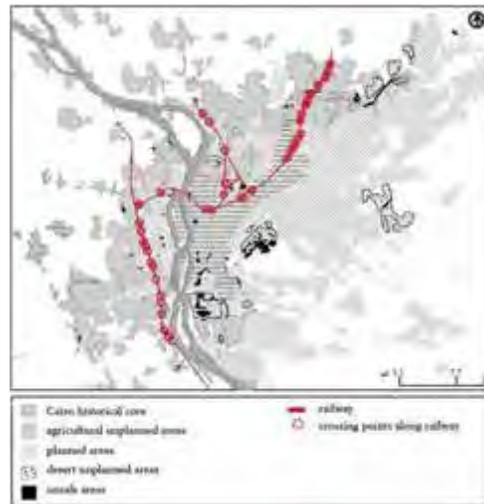


Fig 2. Crossing points along railway (source: researchers)

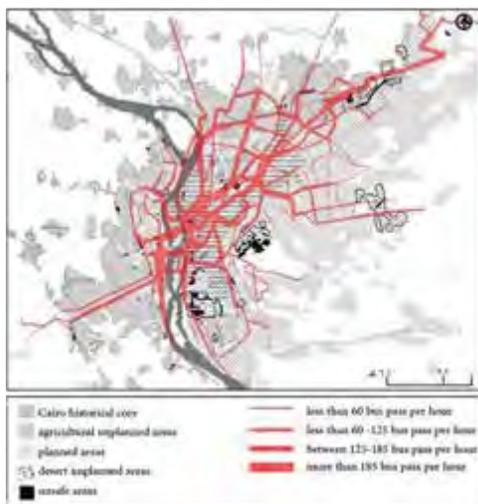


Fig 3. bus routes in relation with main street (source: researchers based on (25))

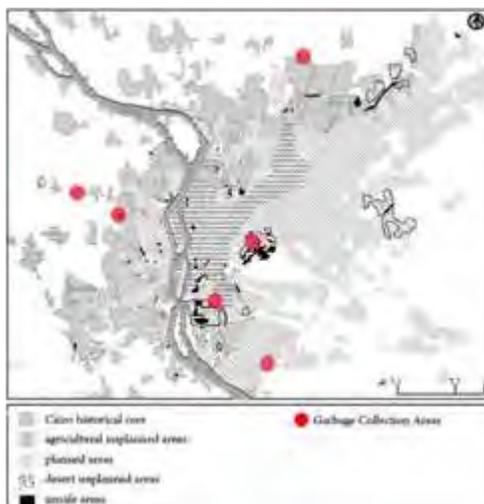


Fig 4. Garbage collection areas (source: researchers based on (2))

NEIGHBORING PATTERNS BETWEEN PLANNED AND UNPLANNED AREAS

Based on reviewing the previous patterns and layers of reciprocal relations, neighboring patterns between planned areas and unplanned areas illustrated as shown in fig 5. 1) Engulfing informality: unplanned areas are surrounded completely by planned areas. Unplanned initially started as ancient villages that originated before the planned areas limiting the growth around them such as Mit Oqba and Al-Houtia in Al-Agouza district, 2) Entangled: In this pattern, unplanned areas overlap with the planned area and the main networks of movement break down. This typology is mainly set from the east by the metro line and the west by the railway line and witnesses a heavy movement of public transport on intersessional main streets. In this case the border is blurred. as examples of this pattern: Al-Zawiya Al-Hamra, Sharabeya, Hadayek Al-Kobba, Al-Matareya, Shubra El-Kheima 3) Adjacency with a physical boundary: where the unplanned construction in these areas is linked to the eastern planned areas crossing the railway through pedestrian stairs and bridges for cars. This type is represented evidently from the case study of Ard Al- Lewaa and El-Mohandeseen, and other areas such as, Boulaq Dakroul and Dokki. 4) Neighboring without a physical boundary: the unplanned areas of this pattern appear as an extension of the planned areas where the established infrastructure affected that growth such as Dar al-Salaam, Maadi, Imbaba and Agouza. 5) Partial reverse engulfing: this pattern is semi opposite to the pattern (Engulfing informality) where the planned area is partially surrounded by the unplanned areas. The daily movement happened from the unplanned towards the planned areas where the street network is accessed by various mobility and transportations options. This pattern represented in areas like Omrania, part of Boulaq El Dakroul (Faisal), Talbiya, Mariouteya, where they surround the formal parts around Haram Street.

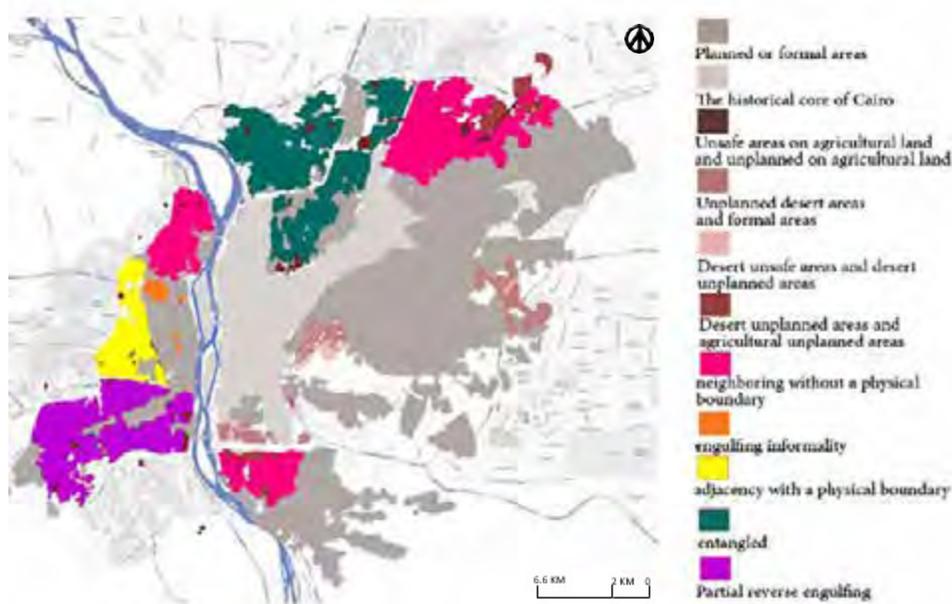


Fig 5. Neighboring patterns between planned and unplanned areas in Cairo (source: researchers)

CASE STUDY: 10 YEARS REVIEW OF THE IN-BETWEEN SPACE OF ARD AL-LEWAA AND EL-MOHANDESEEN.

The case study investigates neighboring patterns on the meso-scale of the district through a chronological analysis of the intersection of juxtaposition, capturing the changes over a decade of government projects and their corresponding local initiatives within the interface between El-Mohandeseen (planned area) and Ard Al-Lewaa (unplanned area). This case is an example of the adjacency neighboring pattern previously defined. The researchers monitored what happened to three main elements: border (highway axes), crossing points and vacant lands.

Ard El Lewaa area is one of the unplanned areas that originally grew on agricultural land in western Cairo. It is divided by the 26th of July axis, and surrounded on the west by the Ring Road, separating it from the extensions of the village of Al-Moatamdia. Boulaq El Dakroul district lies to its south(6).

The Zomor Axes (new highway on a canal route): The Zomor canal was an extended waterway siding the railway route. In 2012, The Giza Governor received the cabinet approval to convert the canal into a highway. Hence, the canal was subsequently backfilled informally by individuals turning it into parking spaces as shown in fig 7. In 2019, construction started in al-Zomor highway axis. Till the end of 2021, the highway is still under construction affecting the road network where the main streets became wider and paved. Despite incorporating bridges and staircases linking Ard Al-Lewaa to the new axes, there still exists locations and capacities that are not clearly defined.

Crossing Points: The second component is in-between neighboring patterns. Crossing points connecting Ard Al-Lewaa with El-Mohandeseen vary between pedestrian crossings and car bridges. These crossings arose sequentially and according to different spatial and temporal conditions in terms of their emergence or development that occurred later, or the users' experience.

The crossing point in Ard Al-Lewaa (*mazlakan Ard Al-Lewaa*) is a vehicle and pedestrian hub for transportation. Since 2010's, this crossing point experienced changes:

2011: The crossing was open to the surface traffic of cars and pedestrians, where the movement of trains intersects with it. The crossing on either side was occupied by informal gatherings of street vendors, microbus and tuk-tuk stops.

2013: The crossing was exposed to many circumstances in 2013, starting with a train collision with a taxi, killing a family of four on January 16th (15). The residents protested the government neglect, which led to the suspension of trains. The response of authorities was to develop the crossing but needed a fund of 2 million pounds divided between the governorate and the Ministry of Transportation suggesting implementing an electronic gateway instead of the traditional methods to reduce accidents (16). One of the political parties at that time intervened by installing two iron barriers (*Shaduf*) as shown in fig 8, followed by a campaign of cleaning, landscaping, and graffiti paintings by local initiatives. In April, the largest campaign for street vendors evacuation took place only to return shortly afterwards leading to an outbreak of clashes between the street vendors and the security forces that resulted in injuries on both parties. Following this incident, Central Security cars continued patrolling the area for a long time on the crossing of Ard Al-Lewaa, where the crossing remained empty without any street vendors as shown in fig 6.

2014: The Mazlakan was closed and replaced with a bridge for cars for outside crossing from Ard Al-Lewaa and another pedestrian bridge. This project is one of the projects submitted by the Emirati scholarship to the Egyptian government for the development of railway stations (7), which was carried out by the armed forces aiming to prevent accidents. The pedestrian bridge did not accommodate the large number of pedestrians as shown in fig 9, which the designer did not take into account, so the surface crossing opened again until adding another way for pedestrian stair access. In parallel with implementation, local initiatives by the Popular Coalition of Ard Al-Lewaa (PCAL) on the ground were trying to emerge themselves in decision-making through different channels. This involved communicating with involved authorities and previous MP, getting voluntary technical support, informing the community with updates and media interviews. All these efforts were made to clarify expected problems of what is under implementation such as isolating Ard Al-Lewaa specially from El-Mohandeseen side. The unacceptable experience with the traditional stairs along the railway was attributed to inaccessibility for the elderly and disabled people and expansion of street vendors and informal stops of transportation means. Despite offering sustainable solutions, the initial implementation process ignored initiated design and community claims represented in "mat'zelnash' (don't segregate us) campaigning to prevent total closure of the surface crossing.

2015: The re-opening of the pedestrian crossing was developed to be wider. To gain community acceptance, two accessibility related items, elevators and escalators were added. Unfortunately, they did not work well and broke down, despite warning of being unsustainable in terms of maintenance.

Vacant lands: The third component of in-between neighboring patterns is the area in-between Ard Al-Lewaa and El-Mohandeseen. In 2012, PCAL developed a plan for Ard Al-Lewaa through ISDF for making a good use of vacant lands. One of vacant lands is what is known as endowment or *Awqaf* land representing the last plot of land (around 12 feddan) lying in between al-Zomor canal and the railway. Awqaf Authority was initiating residential buildings in this area. Based on the PCAL proposal, the prime minister decided to convert the land into a service hub (1,12,13). The process of officially replacing and converting the land into public ownership was suspended for years until 2019, when it was merged into two projects: Zomor canal axis and the new Egyptian railway station in Bashtil triangle.



*Fig 6. The surface crossing in 2013
(Photo by: researchers)*



Fig 7. Al-Zomor canal and the surface crossing in 2012 (right) and (2013) left (Photo by: Hamdy Reda)



*Fig 8. the surface crossing metalgateway in 2013
(Photo by: Mohamed Omar)*



Fig 9. rowdedness on the opening day of pedestrian crossing in 2014 (Photo by: researchers)

DISCUSSION:

Official authorities' classifications of urban patterns were driven by the type of interventions. While researchers focused on analyzing the current situation and clarifying the differences between each type of urbanization. Thus, linking urban classifications with development requires considering various characteristics and features of the urban pattern; either formal or informal, toward enhancing integration in the city. Moreover, looking at the impact of an area's subordination to more than one official administrative unit has proved to hinder required attention and budgets for development. The case of Ezbet Khairallah and its suffering from neglect by local administrations to the benefit of their own district areas such as Al-Basateen, Old Cairo, Dar Al-Salaam or Al-Khalifa, which prompted the residents of Ezbet Khairallah to demand that their area be recognized as an independent district. They even argued to be affiliated with only one district, to enable their neighborhood to obtain a greater percentage of allocated resources and budget (22). This analysis has risen a few related issues when marking administrative boundaries and the relation between different planned/ unplanned urban patterns. How would these boundaries facilitate integration among the city; how will this be reflected in budgeting according to programmes that prioritize needs and available resources are two key considerations. Remarketing administrative boundaries is not a Cairo exclusive issue, as informality exists in many cities in Egypt and delivering the criteria that defines the new remarketing with upgrading intention and impact on district planning is essential.

Cairo lacks an inclusive efficient transport system, since public transport systems are, by their operation system, linear systems, consisting of a series of far spaced stations along a linear route. Problems occur when people want to reach destinations in between these stops, or even in areas that are underserved. This leads to bridging this gap by semi-formal transportation (microbus and minibus) and informal means like (tuk-tuk), with the relevant generation of many dense activities and movement around crossing points (14). While the neighboring pattern between planned and unplanned is defined in several cases particularly based on mobility routes and corridors, it reflects a needs-based relationship with high impacts on both sides. Crossing points can in this case provide a medium to enhance accessibility as a development hub between junctions promoting connectivity and fluid movement. since surface crossing (*mazalakan*) was replaced with crossing stairs where negatively affected traffic flow, especially at peak times. One of the daily scenes that were monitored at these points is the influx of many employees and students of the unplanned areas to the other side, heading to their work and schools/ universities. This resulted in the emergence of a network of low-cost transportation options that suit the affordability of low-income population in these areas such as minibuses and public buses run by cooperative societies for transporting passengers. Moreover, it is clear that mobility and transportation systems in informal areas reflect another conflict between formality and informality in terms of regulations on the policy level on one side, and accessibility, affordability, and safety issues in correlation with city planning from another side.

The informal interventions on the sides of the Ring Road as it passes through informal areas, whether building a staircase, ramps or opening (car repairing, wood and construction/ finishing materials) workshops show a few current gaps. On one side they are an indication of the lack of connection of informal areas to the rest of the city and reflect economic values in these areas and how to be a self-employed and market generator from another hand. Thus, dealing with the ring road has to change from being seen as an edge that limits growth or just a formal cut through as a dominant feature of formality within informality. . However, the challenge that lies ahead is how to maintain the movement flow and safety while serving informal areas and their dwellers needs.

Garbage collection is reflected in the issue of juxtaposition between the districts, so that there is a dependency relationship between the rest of Cairo and the areas where waste is collected and recycled. The Case Study revealed the issue of juxtaposition as a neighboring pattern on the ground reflecting conflict of relations between these patterns, in addition to exploring opportunities to solve this conflict by emerging the spatial components with community initiatives. Analysis also showed another type of interface between government projects representing the formal side and local initiatives representing the

informal side. While the local initiative to convert the vacant land *Awqaf* land to community services park was known to authorities including Giza governorate and ministry of housing, serious willingness was not present at action. Projects like replacing closing surface crossing with bridge and stairs, constructing Alzomor canal new corridor and building the new rail station happened without any considerable coordination. The absence of a dialogue platform where community could be part of decision making in the context of any Local popular council for a decade.

CONCLUSION

The demarcation of administrative boundaries is considered one of the pillars in transforming community development towards promoting integration and inclusion in the city not only for Cairo, but also in all cities where informality constitutes a high percentage in the urban fabric. Having criteria for this demarcation to be aligned with district needs, available resources, as well as established budgets is essential in driving development according to neighboring relations. On the contrary with upgrading areas individually, adopting juxtaposition unit between two or more areas as a development unit plays a significant role towards contextualizing criteria of integration and inclusiveness especially in areas where conflict is generated by segregation. Neighboring patterns as a framework aims to avoid the negative effects of informal interventions and extensions from one side and enhancing local needs within the framework of maximizing resources from another side.

In the methodology, being an active actor in community initiatives opened the opportunity to test ideas and ambitions on a local scale to be raised and resolved on a national and city scale. It emphasized the vitality of the role of communication and coordination between various stakeholders to achieve the implementation of locally responsive solutions that facilitate the shift towards a more inclusive city.

The interface between formal and informal areas in the case study presents in between space within conditional cases that deal with crossing borders, interventions around corridors and their conflicting relationship locally and scarcity of public vacant lands.

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LANDSCAPE STRATEGIES AS A ROADMAP CONTROLLING WATER CONSUMPTION IN SEMI-PRIVATE AREAS

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ABSTRACT

Eco-cities are now dominant bodies concerning cities' resilience and sustainability, they are an essential topic on both governmental and researching scales. Researchers and landscapers are focusing nowadays on Water management and utilization strategies in urban landscape. However most of them are focusing on a unit example rather than an ecological vision or a strategic approach. (Xuebao, B., et al., 2009)

Globally, ecosystems and water are facing a greater pressure than ever before (Daniel, F., et al., 2020). In Egypt, the pure water production falls beneath the benchmark (Mostafa, K., et al., 2021). In this capacity, it was recommended to highlight how landscape strategies may enhance facing water scarcity. Besides, around 25% of water usage in countries is for landscape of public and semi-private areas ((EPA), 2007). The study has a literature review part that defines water poverty problem in Egypt and its consumption sources. In parallel, it highlights xeriscape and agriscape as two different strategies in dealing with landscape areas, and a suggestion of combining them, how much people would accept this strategy, and how much people would support its implementation is introduced in the second part of the study. Accordingly, this research aims to increase our understanding of how landscape strategies have direct impact on communities' resilience not only through controlling resources, but also through civil engagement in these strategies and how it would create a strong bond between people with each other and between people with their surrounding spaces, from which a health and well-being community is generated.

KEYWORDS

Landscape strategies, Xeriscape, water scarcity, Ecocities, Resilience cities

INTRODUCTION

Worldwide, the conversion of land-use intensification and habitat are leading to changes in ecosystem service supply and loss in biodiversity (Neyret, M., et al., 2021). A main challenge is how to conserve the global biodiversity, in the shadow of escalating consumption rates to the highly incensement in human population demands. (Mathew, G., et al.,2021)

In Egypt people always mention the Nile proudly, saying that the Nile is a gift for their country. A critical question is highlighted, 'For how extend would the Nile water cover the need of flourishing cities and the growing demand for development?' (Molden, D., 2019)

Major challenges facing Egypt nowadays concerning management of the available limited resources of water, these won't only affect the communities' development but it affects its existence itself. (M. A. Ashour, S. T. El Attar, Y.

M. Rafaat, and M. N. Mohamed, 2009). The River Nile is the main water resources for Egypt, it is limited to 55.5 billion m3 / year. The fast population growth, has reached 101 million in 2020 and expected to reach 110 million in 2025, and increasing water consumption in many developing fields as; domestic, industrial, agricultural and others it pushes the government to manage and increase the efficiency of using its water resources. (Bayoumi B.Attia, 2004 ; Dakkak, A., 2020)

With better strategic plans, better planning, and a good management the same amount of water that is delivered to the city would be reredirected and reused to cover water demand without damaging the ecosystems. (Molden, D., 2019). As an example, the reuse of agricultural drainage water to the extent that it interferes with optimal crop growth and may causes degradation (Sijtsma, B.R., et al, 1995 ; Abd El-Moneim, A., et al., 2019) should be re-study to avoid generating problems when solving another. Here, we can build-up strategies to create ecological cities/ communities through different aspects. Accordingly, the following parts of the study will highlight Landscape strategies as a roadmap controlling water consumption in semi-private areas in Egypt.

WATER SCARCITY AS A PROBLEM

Water bounty is essential for cities' progress and advancement to face problems such as; climatic changes, agricultural sector, and water scarcity which increase environmental stress. Here comes managing water that should aim for a circular economy in parallel to improving the resilience of alternative water supply. (Ferreiro, C., et al, 2021) Water scarcity occurs when communities reach their limits of water availability physically. In this shadow, development of cities can help in solving water scarcity problems, but as well it can create water scarcity. This was the contradicted situations in California and Egypt, within different insights. Each government starts on solving and facing the essential problem of water scarcity, in Los Angeles for example, the solution was going farther and tap water from distant afield sources. But, in Egypt the status is restricted with limited options, as there is more demanding from the upstream countries, besides too many countries' demands long-term limits where they over-rely on groundwater, and remaining for Egypt a serious water challenge, where the complexity of water scarcity management increases many times (Molden, D., 2019)

Egypt is an arid hot country, located as the last downstream country of the longest river in the world. The rainfall along the Mediterranean Coast and the amounts of deep groundwater, besides the Nile are annual water supply for Egypt. Besides, although previous mentioned resources, Egypt still suffers a negative water balance. (Abd El-Moneim, A., et al., 2019) Although quantity of produced pure water production increased in some of the years, Egypt is already suffering of lying below the water poverty line, which is 1,000 cubic m/ person/year, as individual shares of fresh water has been decreased in Egypt as shown in Fig. (1) (Ahram Online, 2016; CAPMAS, 2020)

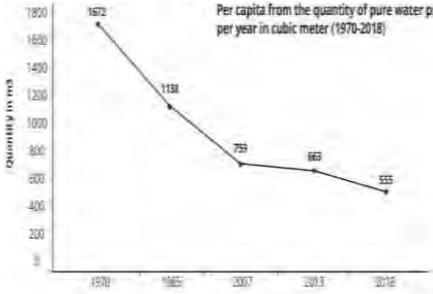


Figure (1); Average per capita from the quantity of pure water produces (1970-2018) Source: CAPMAS, 2020

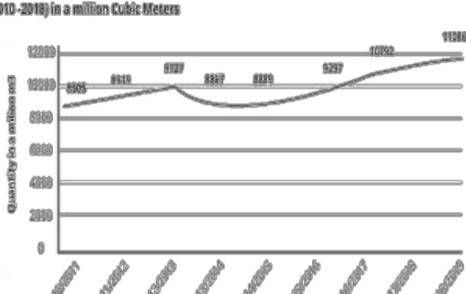


Figure (2); Quantity of produces pure water (2010-2018) in a million cubic meter Source: CAPMAS, 2020

Again, water consumption has increased in Egypt due to the increase in population and the improvement in the standard of living, as well as the government's policy of encouraging industry and expanding the agricultural sector. The volume of water resources currently available is about 55.5 billion cubic meters/year from the Nile River, 1.3 billion cubic meters/year from actual rainfall in the northern parts of the Nile Delta, as well as 2 billion cubic meters/year from non-renewable groundwater, from Western Sahara and Sinai, a total of 58.8 billion cubic meters / year. While the water needs of the different sectors amount to 79.5 billion cubic meters / year. Thus, the gap between supply and demand is about 20 billion cubic meters/year, as shown in Fig. (3) This gap is filled by water treatment. (The Egyptian Centre for thoughts and strategic studies, 2019)

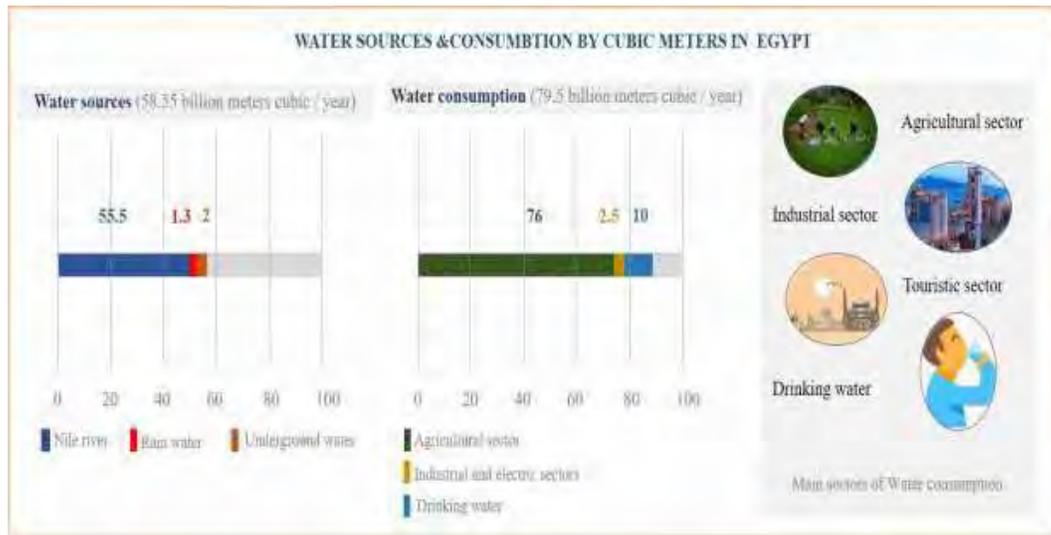


Figure (3): Amount of water sources and consumption sectors in Egypt
 Source: Researcher, 2021- Derived after The Egyptian Centre for thoughts and strategic studies, 2019

There are many aspects of the crisis of wasting clean water in Egypt as the following reasons: (The Egyptian Centre for thoughts and strategic studies, 2019)

- Water pipes and infrastructure are deteriorating and leaking water, which increases the percentage of waste in the amount of pure water.
- The use of large quantities in street spraying and car washing, in addition to the continuation of flood irrigation in lands with sandy soils, or the cultivation of crops that are of a water-hungry nature.
- The use of huge amounts of water in golf courses, tourist resorts and artificial lakes.
- The high percentage of pollutants in the waters of the Nile River and the dumping of sewage and agricultural wastes and factory waste, despite their partial treatment.
- The spread of random, as well as regulated, water laundries at gas stations, which consume thousands of cubic meters of water, which are sufficient to cultivate thousands of acres annually.

LANDSCAPE MANAGEMENT

In the 21st century, Sustainable land management is one of the most challenges facing humanity. Researchers and decision makers need to work together and explicate fragmented issues through clear management approach to take resilience decisions despite of uncertainty ones. (Daniel, F., et al., 2020). Equally, landscape strategies become a roadmap in order to monitor resource limitation and evaluate concerns as to develop a resilience vision which articulate objectives, and propose principles for a sustainable future. (Vogiatzakis, L., Pungetti, G., and Mannion, A. M., 2008) The main goal of a landscape management is to complete an ecological system that protects the environment and to recover valuable resources from waste (e.g., nutrients, water, energy). Besides, managing the needs of community which dramatically vary among population. (Nelson, K., Murray A., 2008)

Among benefits, effective landscaping and planting contributes to the cooling of urban areas (Friedman, A., 2020). In arid and semi-arid regions, as Egypt, lowering vegetation coverage causes an increase in surfaces' temperatures and incensement in energy costs as a consequence (Wang, C., et al, 2021). Therefore, the question is: **How can we minimize water consumption in residential outdoor spaces without leaving a negative impact on the community?**

Private and semi-private areas of landscape are mostly gathering points. They are usually required to be attractive, functionally, and durable, sometimes these areas carry vegetables gardens, but they are designed with less water requirement than a public area of landscape. (Ozyavuz, M., 2012)

A socio-ecological systems' transformation is more likely when users feel their ownership to their surrounding environment, community participation and Collaboration approaches may allow to a better use of communities' knowledge, increasing social learning, and much more responsibilities during the implementation process. (Bieling, C., Plieninger, T., 2017; Arts, B.; Buizer, M.; Horlings, I.; Ingram, V.; van Oosten, C.; Opdam, P. 2017)

In 2006, the Air Canada En Route magazine published an article that highlights some questions regarding using the booming GRASS; Asking if it is a symbol of prosperity, or an ecological nightmare, and is it a cultural obsession or a booming industry? In the same article, the author highlighted the XERISCAPE as an alternative method for decorating yards instead of filling them with GRASS. (Wood, D., 2006)

Accordingly, variety in scenarios should exist in order to generate Landscape management strategies to face water scarcity in Egypt, without prejudice food production or affecting negatively on the climatic or social aspects. Thus, the next part of the study will highlight the xeriscape as a scenario for reducing water consumption, and the agriscape as a replacement for Grass with a productive food planting.

Scenario A; XEIRSCAPE- A xeriscape, as a landscape type, helps in reducing water consumption up to 50 percent without affecting your landscape beauty or functionality. (Wade, I., et al, 2002) In urban areas, in Texas as an example, about 25 percent of water consumption is used in watering gardens and landscape. (Texas agricultural extension service, 2003). Besides, it is well encouraging to select this type of landscape as it is having many benefits such as (Ozyavuz, M., 2012);



Figure (4); Benefits of using Xeriscape
Source: Researcher, 2021. Derived after Ozyavuz, M., 2012

Accordingly, a xeriscape strategy has planned to divide the water use of landscape into three categories; High water use zones (regular watering), moderate water use zones (occasional watering), and low water use zones (natural rainfall or others) (Ozyavuz, M., 2012). For a xeriscape type of landscape there are seven principles to be combined to give a unique product, they are; *Planning and design, soil analysis, practical turf areas, appropriate plant selection, efficient irrigation, use of mulches, and appropriate maintenance* (Smith, C.R., Larson, R., 2004; Ozyavuz, M., 2012; Abd El Aziz, N., 2016)

Scenario B; AGRISCAPE- There is an important distinction in landscape operation, and practice it in a way that simultaneously meets multiple objectives for landscape management. Through the past years, Eco-Agriculture Partners have focused on the challenge of a transition into food security and an agricultural production through a landscape approach. Throughout experiences, the world began to systematize the conceptual frameworks into practical actions. Five critical elements for agriculture landscape management were important to land use; (McNeely, J. and S.J. Scherr. 2001; Eco-agricultural partners, 2013)

1. Shared objectives that defined multiple benefits
2. Farms, forest, and fields should be designed to contribute various dimensions as; food production, human well- being, biodiversity conservation, climate change mitigation, and others.
3. Managing social, ecological, and economical interactions between different parts of landscape
4. Dialogue and collaboration between different community stakeholders when taking or monitoring a decision
5. Shaping of public and markets policies in order to achieve the diverse of land settings

CASE STUDY

From previous part of the study it was highlighted how consumption of water is forming a pivotal point in countries strategies, merging the two scenarios A&B in landscape gardens of semi-private areas will help in reducing water consumption, increase food production, and encourage social interaction. Accordingly, the methodology of the case study will be divided into two sections. The first section (A) is a background for the area of study and pillars required to form and apply Landscape management strategies. While the second section (B), will describe the onsite case and will carry about a survey to find more about stakeholders' priorities when merging the two scenarios A&B (xeriscape & agriscape), by which conclusion would be effectively reflecting implementation capabilities for a promising fulfilling Landscape management strategies as a roadmap controlling water consumption in Egypt.

Section (A); Background

Communities and enclosed urban spaces are domain physically and psychologically affecting quality of life (Shawket, M., 2019). Most Egyptian new urban cities are facing water shortage problems as they are located in desert regions, thus architects and landscapers have role in water consuming through neighbourhoods' central public gardens design (Hesham, A., Mokhtar, N., and Abou-Hussein, S., 2013). In most of new urban Egyptian cities central gardens are a driven key in planning districts, although there is a lack in their role as recreational areas which enhance public relations and contain many activities as; pedestrian walkways, shading elements- natural as trees or artificial as wooden pergolas-, children playgrounds –although urban environments have major contexts in growing up new generations- (Shawket, I. M., et al., 2019), daily fitness activities, bike riding practice, and others.

New Cairo is a well utilized example that can be taken according to what have been previously mentioned, it is a new urban city initially was in deserts with hot arid temperature and rocky soil, besides, it has a social integration lack, habitants love plantation and always looking for public activities. As well, it has a good percentage of urban spaces where its neighbourhood central gardens based plans serves housing categories variations. It has the pillars of landscape management interaction in semi- private areas of landscape required to form and apply Landscape management strategies as a roadmap controlling water consumption to reach a resilient and sustainable city as shown in the following figure.



Figure (5); Pillars of landscape management interaction in semi- private areas of landscape
 Source: Researcher, 2021

Settlements' planning clearly reflect previous mentioned idea, the following map shows the amount of greenery in the districts of the first settlement. (As shown in figure 6)

For governmental housing in first settlement- New Cairo, the majority consists of 5 floors building with a central garden accessed only by pedestrians. These gardens may only contain some wooden pergolas and grass as a greenery element, as shown in figure (7). For private buildings, the planning mainly consists of either 4-5 buildings, or villas districts – as shown in figure (8) – which mainly consists of 3 floors.



Figure (6); Planning of some districts in the first settlement, New Cairo Source: Google maps, August 2021



Figure (7); Planned governmental housing gardens in first settlement- New Cairo Source: Google maps, August 2021



Figure (8); Planned private buildings (villas) gardens in first settlement- New Cairo Source: Google maps, August 2021

SECTION (B); ONSITE WORK

This semi-private landscape garden is the land of convergence between its on-sides residents. It is the place where they gather in events or religious occasions. It is whole grass zone with no diverse in its land settings, even there is no existence for a path or a sitting element. Residents of this area started to have dialogues to control the beauty of the visual image of this plot, one of their decisions was colouring electricity boxes as shown in fig. (9), and to manage its watering, lightening, and maintenance as well. From which, the researcher finds this community a fertilized one concern the willing of upgrading the garden.



Figure (9); Electrical boxes coloured by the residents Source: Researcher, 2021



Figure (10); Garden's on-sides residents gathering on Ramadan Iftar in 2021
Source: Researcher, 2021

In this study, a survey prepared to measure habitats' acceptance for merging and applying of scenario 1, through xeriscape principles, and scenario 2, through the basic elements of agriscape approach, in order to format a Landscape management strategy for their forehead garden as a part of a general roadmap controlling water consumption in semi-private areas of landscape in Egypt. As Xeriscape holds 7 main principles and Agriscape holds five main elements, twelve elements were defined to be graded on scale from 1 (least acceptance) till 5 (highly accept and recommend). The semi-private garden has three main forehead villas, more than 50% of their residents were engaged in the survey study with total number of twenty-seven persons, 58.8% are males and 41.2 % are females. As well, it was highly encouraging to imbed children in this study -as they do reflect a percentage of users-. Thus, age range between 10:20 years reflects 23.5%, 29.4% between 21:35 years, 35.3% between 36:50 years, and 11.8% older than 50 years old. With the same percentages, the survey was extended to ask about diversity in land settings and their priorities.



Figure (11); Habitants acceptance of xeriscape and agriscape principles Source: Researcher, 2021

When meeting people and start taking with them about xeriscape and agriscape the researcher noticed that they preferred xeriscape to be applied in their forehead garden, but when analysing their numerical survey with the principles of each strategy it delivered that agriscape strategy is higher than the xeriscape with 4%. Only small areas of food plantation are recommended responding to climatic change and water consumption.

- Although agriscape has a total support 80%, it was noticed that “Appropriate plant selection for food production”, which is the core of this approach is the least element supported with only 3.2%.
- Diversity of land settings is the highest ranked element in the survey, and this reflect age variety in the residential zone.
- Introducing mulches is a strong accepted and supported, by the residents, proposal that combines beauty of the scene with the concept of water consumption.
- Overall, the twelve elements were all above average rated, which reflects the community acceptance to apply them.
- Some residents have comments as follows;
 - The community participation would be in case of expert existence only.
 - Agriscape (food planting) depending on availability of water and maintenance, and is not essential or even.
 - Appropriate maintenance is essential to sustain the scene of beauty and the functionality in the area.

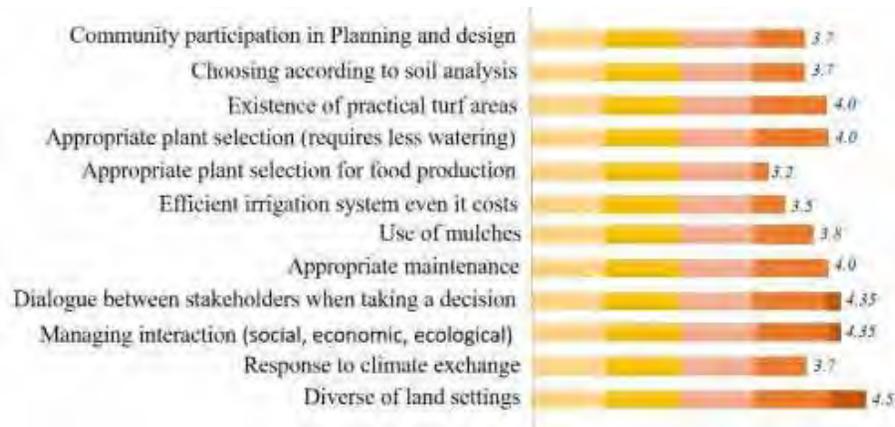


Figure (12); The 12 principles of merging the xeriscape and agriscape strategy Source: Researcher, 2021

The next part of the survey, fig. (13), introduces different activities to form a diverse in the setting of the space, and as well each was graded according to the demand of its existence.

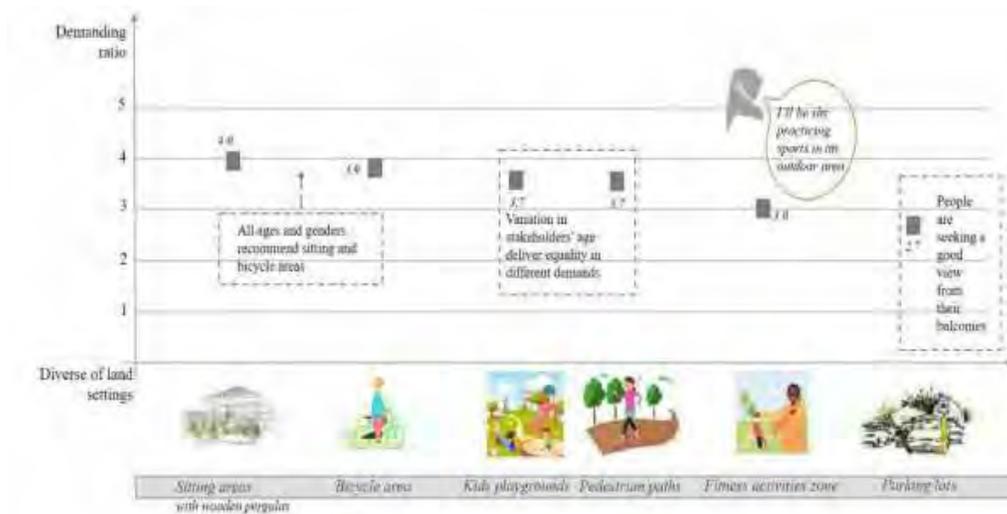


Figure (13); existence of diverse activities Source: Researcher, 2021

- Diversity in activities will be reflected on the settings of the area, and it will positively affect water consumption. If 50% of the grass is substituted, then 50% of water consumption will be decreased.
- Activities demanding ratio above three are the recommended, and this part of the survey could be generated before any design as a part of integration in design and planning throughout principles of xeriscape and agriscape.
- Car parking lots are not welcomed to be part of the area except for some of the elder residents.
- Kids playgrounds and pedestrian paths have the same importance as most of the family parents are in 30s with their small children.
- Although the high society class resident of the new settlement, the social background of an Eastern country still affects them, where women feel shy and/ or non-comfort having their workouts in an open space and in front of her neighbours.
- A sitting area –with a wooden pergola- is the highest setting required to exist by the residents.
- Age range play a great role in the spaces' requirements. Thus, before taking any decisions all stakeholders should be involved in it to ensure its success.

CONCLUSION

The preceding study analyse how integrated Landscape strategies could control water consumption in semi-private areas besides building a social bond between people with each other and people with the space itself. Talking the ‘Missing Strategies’ in environmental policy is itself the route conducting solutions for several aspects, for instance, highlighting different principles by which stakeholders will totally support are encouraged to be implemented and will directly decrease the amount of water consumption –in this dimension- to 50%. Overall, combining the basic elements for the strategies will form out an appropriate semi-private spaces that fulfils social aspects besides environmental ones. The study demonstrates the presences of many conflicts as the high percentages given to the agriscap approach, and in parallel the lowest graded element was food plantation. This reflects the disapproval of an element without having enough knowledge about it as; (it requires more watering, it will cost a lot, it needs a lot of maintenance). Another conflict is in the real need of the stakeholders to some elements as the sitting elements, and the insistence of the government to do not implement it in the design because of its maintenance and high initial cost. And at the same the planning insists of having a centric garden lot, as previously mentioned, with trees and palms regardless the amount of water consumption, although we are one of the countries that are facing water poverty. Briefly, this was a primary study that reflects light on the importance of putting new strategies to conducted solutions which integrate with nowadays Eco-cities. Yet, it is the time for Putting integrated landscape management into practice in order to reach maximum benefits.

RECOMMENDATION

To reach a satisfactory result, there are several recommendations on different levels as follows;

Community and habitants

Accepting of new methodologies which benefits their communities and fulfil their needs, and Integrate in different applications and give a hand in ecological implementations.

Planners and landscapers

Support designers with suitable plantation selection, Support the planning with enough open spaces, Update designs regarding climate exchanges, respecting soil analysis, giving knowledge to community members about food planting with watering and maintenance requirements, respecting stakeholders’ demands, and Build up settings variations.

Country politicians

Importance of persuading landscape trends and their role in decreasing water consumption as xeriscape, and supporting the community well-being and productivity as Agriscap, and Giving legal authorization for stakeholders to integrate in designing decisions.

Researchers and experts

Making further researches towards an ecological city, Researching on the scope of water poverty solutions, putting methodologies and strategies to be applied, and Study risk management of different natural resources lack.

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EMERGING NATURE-BASED SOLUTIONS OF ECO-LANDSCAPE: APPLIED TO FORGOTTEN EPHEMERAL AND DRY STREAMS IN CAIRO-EGYPT

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ABSTRACT

Due to the recently increased challenges of human health and climate change issues, the role of nature-based solutions (NBS) has become a worldwide growing trend in the eco-landscape field. This paper aims to propose an integration of NBS to one of the potential marginalized natural open spaces, it is the forgotten dry streams/wadis in Egypt. The selected segments of the dry wadi are located in Helwan, one of the densified polluted urban cities of Greater Cairo. Apparently, the extreme precipitation events, which occurred in the past few years, assured the functionality of dry streams/wadis as a flood-control basin. These dry wadis can potentially be restored as a blue-green infrastructure and a natural open space. This combined eco-landscape approach is not limited to the improvement of the environmental crisis, but it also re-embeds the social aspect as a pillar of NBS. The proposal adopts participatory actions, sustainable practices and feasible management, where collaborative practice and bottom-up actions are much needed in developing countries. The conclusion asserts the emerged socio-ecological paradigm of NBS. This eco-landscape practice would provide broad resilience values, reduce environmental risks and mitigate the current post-pandemic health issues. The paper recommends a gradual process to allow more time for assessment and refinement in a real context, as this emerging NBS still needs to be widely applied and evaluated in Egypt.

KEYWORDS

eco-landscape; nature-based solutions; dry stream/wadi; marginalized natural open space; Helwan-Egypt

INTRODUCTION

Eco-landscape research and practice are gaining more attention worldwide, in response to the combined current situation of post-Covid 19 human health and the increasing environmental challenges. One of the growing trends in the eco-landscape field is nature-based solutions (NBS). Despite being a relatively new branch; NBS offers a bridging tool between health and climate change mitigation [1]. The last climate talks (COP26) that took place in Glasgow, UK, on Oct. 31

Nov. 12, 2021, have discussed NBS as the use of the power of nature to solve global environmental hazards and impacts. Although health and climate resilience is a global response, it can be addressed differently in each part of the world. Worth mentioning that Egypt will host the next year's UN climate summit, in Sharm el-Sheikh. This summit will focus on resilience to climate impacts [2]. It's a great chance to promote actions on land.

Cairo, Egypt's capital, endures increased densification, it inhabits more than 20 million, nearly one-fourth of the country's population. It is ranked as one of the most polluted cities, where more than 60% of the nation's industries are located [3]. Moreover, Cairo suffers from the lack of open green spaces and rapid building over agricultural land. These issues magnify the health risk and climate change.

Many Cairene urbanists and landscape architects agree that the area of urban green space for each person is less than the desired amount, which affects both the environment and the citizens' health and well-being. According to the European standards, cities shall provide a minimum urban green space of 9 m²/person, that is extended up to 40-50 m²/ person in fortunate cases in Europe [4]. Cairo, as a polluted city, needs more attention to urban green spaces. Nevertheless, Until 2000 Cairene people had on average 0.8–1.5 m² of green space/person [5]. Therefore, Cairo is considered an urban arid or desert region. For example, Helwan is located in south Cairo and is historically a therapeutic green destination. Helwan used to have 1.83 m² of green/person [6]. But, these green areas are decreasing every year. The buildings' invasion of the green spaces left Cairo with increasing socio-ecological problems. The satellite images (Fig. 01) visualize the degradation of green spaces in Helwan, during the past twenty years.



*Fig. 01: The degradation of Helwan green areas in the past 20 years.
Source: Google-earth maps (2002-2012-2021), accessed in November 2021.*

CAIRENE FORGOTTEN EPHEMERAL AND DRY STREAMS/WADIS

The witnessed heavy rainfall in the past few years sank several parts of Cairo, (exactly on 13th March 2020, 23rd October 2019 and 25th April 2018), and highlighted the weakness in the infrastructure, as shown in (Fig.02). After the precipitation of extreme rainfall, green patches and wild plants and animals are shown on the banks of the dry streams. See (Fig.03) and (Fig.04). Urbanists keep searching for neglected and marginalized opportunities to add green spaces in the city's vacant urban pockets and in-between buildings, to maximize green spaces and connect existing green corridors. The aforementioned situation of extreme events grabs the attention of the ephemeral and dry streams as one of the rare forgotten natural open spaces [7]. Dry wadis are no man's land where garbage and construction waste are illegally dumped, as shown in (Fig.05). Consequently, the Egyptian municipalities remove wastes from the thousands of these rain channels and dry streams every winter to unblock them and avoid flood risk [8].

The studies concerned with streams are usually distributed between hydrology, geology, land use and ecology; the local landscape architects rarely consider them natural open spaces [9]. Many argue that the restoration of the dry streams is assured because their function is recognized as a flood-control basin, especially with climatic change of severe drought/extreme rainfall [10 &11].



Fig.02. Flash floods in Cairo on 13th March 2020.
 Source: [URL.arabnews.com/node/1640806/middle-east](https://www.arabnews.com/node/1640806/middle-east).
 Accessed on November,11, 2021.



Fig.03 Green patches and wild plants on the banks.
 Source: [URL.almasryalyoum.com/news/details/840019](https://www.almasryalyoum.com/news/details/840019).
 Accessed on November,11, 2021.

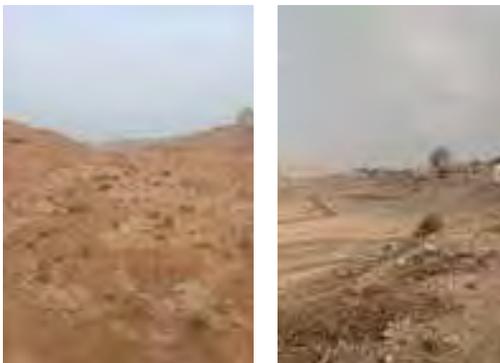


Fig.04. Native drought tolerant wild plants are adapted in many soil types, as those in the selected North Abu-Silli wadi.
 Source: Author.



Fig.05. Garbage are dumped, and wild plants are grow on dry wadis' banks.
 Source: [8]

DRY STREAMS/WADIS INTEGRATED WITH NATURE-BASED SOLUTIONS

Dry streams and wadis are part of the ecosystem, where they support a wide range of natural wild plants that can thrive and grow in arid landscape conditions, as shown in (Fig.04). Although human negative activities threaten this ecosystem.

Researchers used to deal with NBS of blue-green infrastructure as a method of integrating all-natural and semi-natural environmental components within the local urban fabric and ecology, to promote more sustainable green-blue networks and ecosystems.

Accordingly, In view of the current extensive environmental degradation in Helwan, This paper proposes the potential of integrating nature-based solutions (NBS), as an eco-landscape approach, with forgotten dry streams/ wadis in the densified polluted Helwan district. This paper is based on the argument that restoring and sustainably managing dry streams is one of the NBS to reduce flooding risk, strengthen water security and mitigate climate change. Dry streams may also provide open green spaces and recreational areas to enhance local livelihoods. The IUCN defines NBS as: “*Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*”[12].

This paper adopts the above approach, where participatory divergent dialogues are conducted by the author, at a margin of a workshop studying the feasibility of executing an eco-park located on a segment of North Abu-Silli dry wadi, in Helwan. While this study focuses on the NBS role and discusses the possibilities of restoring, naturalizing and managing dry streams. We believe that these dry wadis are also a potential natural blue-green infrastructure, that would increasingly provide recreational, educational and spiritual benefits within the long-term sustainability of conventional eco-practices. Hence, dry wadis can improve both the environment and the community development, as this paper elaborates.

DRY WADIS AS A POTENTIAL HYBRID BLUE-INFRASTRUCTURE

One of the critical concerns of increasing natural green spaces in Egypt is water scarcity, and this concern will be accelerated by the completion of the Grand Ethiopian Renaissance dam. Blue landscape elements are connected to water. They are either artificial water features; like fountains and ponds, or natural watercourses as wadis and rainwater streams. Blue infrastructure works between land and water, hydrology and ecology.

Most of the wadis in south-east Cairo are ephemeral and dry streams. Wadi, as a blue infrastructure, lost its natural connection with the river Nile. The densified urban fabric disconnects this traditional bond. Most of these dry wadi are unconnected to the modern central sewage system as well. Hence, it is hard to consider them as blue infrastructure or natural open spaces, as seen in (Fig.06). However, wadis still can mitigate severe drought/extreme rainfall and flood. The geological degradation and slopes of existing wadis may allow more feasibility of harvesting rain and floodwater, while treated or isolated bases may reduce water loss to the soil. We argue that harvesting rainwater in a catching pond would act as a reservoir to combine landscape. Whereas linking and filtering the rain-drainage infrastructure, from nearby settlements, may not only solve the overloaded drainage and infrastructure problems and reduce the flood risk in extreme events, but it may also provide more water resources to irrigate plants in times of drought. The attached urban fabric foregrounds the integration of wastewater treatment as a blue infrastructure too, where the integration of wadis with treated grey and wastewater from the surrounding domestics and buildings would be one of the considerable opportunities to transfer the dry wadis into natural open spaces without stressing limited resources.

We argue that more studies can be elaborated to efficiently contribute to facing water scarcity, as filtering and reusing hybrid stormwater and grey-water in the irrigation system and agriculture needs. It may even be used for other domestic needs.

The following sketch (Fig.07) illustrates the proposed water resources using a hybrid system of natural watersheds and semi-natural wastewater treatment from the surrounding urban context. We endorse the use of the hybrid system of integrating all available water resources, harvesting floodwater, catching agricultural drainage basins and using treated wetland and grey-water treatment and reuse systems (GTRS), instead of relying on clean water supply in irrigating green areas. As with water scarcity, every single drop counts. Wherever using drip irrigation system would also reduce and efficiently control the irrigation system.



Fig. 06. The six dry wadis in Helwan, south-east Cairo - zooming in a segment of (North Abu-Silli) one of these wadis. Source: Author; adapted based on [7] and NRIAG's survey/ laser scan work.

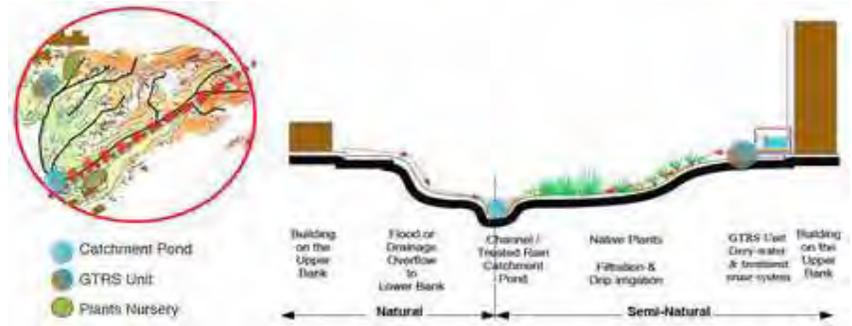


Fig.07. A cross section in a segment of a rainwater stream showing the recommended hybrid natural & semi-natural functions of wadis, during extreme rainfall/drought events. Source: Author

DRY WADIS AS A POTENTIAL GREEN-INFRASTRUCTURE

Green infrastructure is associated with any green landscape element, whether the natural native vegetation, the human activities of planting more species or adopting techniques that mimic the natural process. It varies from a row of trees, hedges, shrubs, ground covers, natural grasslands, green roofs or walls, recreational open spaces, gardens and eco-parks or a complete valley/wadi system [13]. We see potential in employing grassland in different parts of the restored dry streams, to be used simply for rangeland and grazing, to mimic the widely observed traditional practices. This kind of grassland proposal or planting non-edible production fits more with the recommended irrigation system from GTRS.

Recently, access and exposure to natural spaces have become part of global healthy and sustainable city agendas [14]. Natural spaces are one of the most highlighted issues by health organizations in the post-coronavirus age. We advocate selecting indigenous, native and drought-tolerant plants that are best adapted to the climate and suitable for arid landscape. We also recommend conserving the natural slopes and features by planting ground covers to control the soil erosion [15]. The initiative proposal does not stop at readapting the dry wadi; like grasslands, but it proposes providing shaded paths, with a row of local native shading trees, as Royal Poinciana (*Delonix regia*). The soil in Abu-Silli dry wadi consists mainly of limestones. Limestone soil is relatively a low moisture content, it is prone to drought. but the Royal Poinciana tree tolerates both drought and salt. Hence, planting trees and ground covers contributes to shading and controlling soil erosion. The collaborative discussions with biological and agricultural engineerings recommend reducing chemical fertilizer and using more sustainable practices and minimum organic fertilizers to protect the soil quality.

We argue that these shaded pedestrian paths would delineate the pedestrian shortcut paths between the banks of the wadi. Yet, abandoning the cars and motorways from the wadis would avoid frightening wildlife and encourage walkability in an unpolluted environment.

One of the recommended indigenous species too is the Wild Chamomile (*Matricaria chamomilla*). It's a drought-tolerant plant, and its strong scent often contributes to keeping pests and snakes away from the pedestrian areas, without killing them. Such a selection supports the protection of wildlife, native plants and other natural features of the site that conserve the biodiversity.

One of the recognized potentials of using a hybrid system of all available water resources is that it can help in growing more shading trees, ornament grass and non-edible plants to provide a green recreational open space beside the wild plants and grasslands in the conserved parts of the dry streams. Furthermore, we assert that this variation in the green infrastructure could be a seed for any future ecological open place or an eco-park in wide segments of the dry wadis. This green practise would also create a habitat for migratory birds in the different seasons.

The proposal however encourages the brown landscape over the green ones in many segments to suit the arid conditions. For example, we recommend the use of compact soil, rammed earth and up-cycled existing construction waste, in hardscape and landscape furniture.

Correspondingly, we classify these natural and semi-natural landscape elements as an integrative green-blue infrastructures of NBS.

THE INTEGRATIVE SOCIO-ECOLOGICAL APPROACH

The cost of the traditional actions of integrating green areas within densified cities is usually highly expensive. Even so, NBS adopt simple and cost-efficient approaches [16]. In the initiative proposal, more potential is seen in restoring dry wadis merged within a densified urban fabric. The urban settlement is not only recognized as a source of grey-water or a connected drainage system, but it is also a socio-cultural resource. As supported by many researchers, the engagement of the community with multi-disciplinary skills and efforts can speed up natural resilient infrastructures and catalyze sustainable actions. Even the recent studies re-embed the social aspect as a pillar of NBS and ecosystem services [17, 18, 19 & 20].

The Covid-19 pandemic has a dramatic effect on the economy, where many contractual and informal precarious labourers lost their work. Egypt has a deep work vulnerability crisis, the unemployment rate has increased and income has decreased more during the pandemic [21]. Economically, most of Helwan's inhabitants suffer from limited income and fair access to employment opportunities. The proposed eco-project falls within the long-term policies. By engaging the local labourers in eco-jobs, they may learn and exchange knowledge, train others and participate in the execution of such projects.

This paper focuses on increasing the resilience of the overall system, by searching for more societal potentials in the surrounding site. As noticed, Besides the labour force from the local residents, many educational institutes are established during the past decades in Helwan, for example; The Helwan University, The National Research Institute of Astronomy and Geophysics in Helwan (NRIAG), and a number of national and technical vocational schools [22]. This wide range of backgrounds can offer data and experiences in different fields. For example; NRIAG has employees experts in land surveying, microclimate, soil and geophysics. They may provide technical reports of the wadis' contour maps, subsurface water and soil reports, meteorological data, and environmental monitoring data. They may also add to the possibility of using solar panels for night lighting and for running automated irrigation systems. The joint of local non- governmental organizations (NGOs), who have experts in planting, irrigation systems, wastewater treatment, landscape and volunteers are essential. The diverse expertise and skills base will help in conducting participatory workshops to assist in carrying on the future maintenance. Adding to the above, the cooperation with the technical vocational schools' students, through training workshops and summer camps; would provide a talented workforce and add to the students, the local labourers and the whole environment.

The case at hand argues that such bottom-up actions and participatory multi-disciplinary workshops are much needed in Egypt, as a developing country. The participatory approach of collaborative multi-disciplinary workshops plays a major role in empowering the learning process, reducing technology risk and building the local workers' capacities. Besides that, the involvement of the local community from the early design decisions and through sustainable practices of governance would provide direct monitoring from the attached community. We argue that this initiative can be achieved by direct involvement in a set of recommended segments of the dry wadis, as the daily attachment provides a deep understanding of the socio-ecological environment. While building knowledge and awareness by diurnal working on the project ensure the maintenance and continuous evaluation process, and reinforces the ability to encounter future obstacles and challenges. Furthermore, the local participants may act later as a reference or expert by doing for similar cases of blue-green infrastructure restoration that reconnect culture and ecology in long-term sustainable plans. We argue that the participatory workshops suit also the pandemic consequences, as parallel workshops can take place with a limited number of groups and shift working hours to sustain the project. Where the proposed sustainable practices and management aim to achieve the set goals, as summarized in table 01.

Despite the similar characteristics of dry wadis, each wadi has its own circumstances and needs specific situational analysis to choose a suitable solution. And since the local community is not familiar with and not widely engaged in this practise, we argue that a gradual process allows more time for assessment and refinement in real contexts, as this emerging NBS still need to be broadly applied and evaluated in the Egyptian context. And as Maes and Jacobs [23] stated, researchers highlight the importance of the participatory design process. But the socio-ecological system needs to integrate all types and systems of knowledge and values for NBS design, where political, economic and scientific groups should be presented.

This proposal asserts the importance of the practitioner role besides the policymakers, as the authority has the power to take massive action in the densified urban of Cairo. Here, the local residents and experts together with the municipality of Helwan perform as a social pillar to achieve NBS. We argue that more socio-economic benefits would be gained through the collaboration and participation of NGOs with governmental authority approval to ensure the transfer of management rights to communities in the project area. If all activities are conducted under the supervision of Helwan municipality, the local authority, this would also ensure smooth conduction project and monitor the outcomes reporting back to the local community council and Cairo Government. And as Raymond et al. (2017) [24] mentioned, the interaction between NBS and the socio-ecological system is reviewed and a complete list of indicators is presented. However, actions should be assessed to avoid affecting social justice, social cohesion and contributing to the gentrification of urban green space development [25].

CONCLUSION

The rabid environmental crisis and challenges call for accelerated reaction to protect nature and human wellbeing, where every and even minor action can make a difference. This paper addresses diverse potentials of integrating NBS within dry streams/ wadis when applied in densified polluted urban contexts: 1)mitigate climate and flood risk; 2)provide ecosystem- services; 3) promote human health and well-being; 4)sustain socio-ecological benefits, 5)encourage collaborative participatory design and action 6)stir citizen governance and management as supportive ways to a responsive city.

These potentials are seen in response to the parallel blue infrastructure scenarios; Where the potentially presented dry-stream/ wadi can play a critical role in absorbing flood flows, this shall reduce the stress on the drainage infrastructure and the disasters of extreme events of precipitations. While filtering the drained water-flood and reorienting the harvested rainwater in the catchment pond would act as a reservoir, plus the integration of grey-water and wastewater treatment, in the best scenario of drought time, would benefit the plants' irrigation.

Table 01: The proposed sustainable practices of NBS and the expected results

| | The Proposed Sustainable Principles for NBS | The Set Goals - Expected Results (Long and short-term impacts) |
|----|---|--|
| 1 | Restoring and naturalizing dry wadis, plus searching for different water resources. | Reduce flood risk, mitigate climate change, conserve wildlife & biodiversity and increase existing greens landscape. |
| 2 | Reconnect the citizens with nature and wildlife. | Encourage walkability and improve human health and well-being. |
| 3 | Provide recreational open spaces with outdoor positive activities and workshops; as planting, camping, ecological and scientific experiments | Improve learning environment and mental well-being. |
| 4 | Inspire laypeople through working with ecological and multidisciplinary experts | Contribute to environmental education and raise NBS awareness. |
| 5 | Expose wastewater treatment and construction waste recycling to the local community. | Provide mock-ups and a learning process that shall raise ecological awareness. |
| 6 | Encourage the brown landscape rather than the green ones to suit the arid conditions | Support the protection of wildlife, native plants and other natural features of the site. |
| 7 | Remove wastes and appraise the reuse and the up-cycle of construction wastes (wastes in current wadis) | Clean the wadi, Encourage more sustainable practices, that would provide cheap hardscape and landscape furniture. |
| 8 | Train and hire the local laborers in green jobs | Amplify the socio-economic impact. |
| 9 | Involve experts and professionals in multi- disciplinary teamwork with interests in the design, implementation, monitoring and evaluation of NBS during various action plans. | These multidisciplinary participatory and citizen design practices are supportive ways to a responsive city and provide the seed for the project's future management. |
| 10 | If this model is replicated across various dry wadis & Upscaled through corridors and connected spaces and add more green places. | <ul style="list-style-type: none"> • Catalyze development at different sites with best opportunities for development. • Maximize the value and socio-economic and environmental benefits. • Generate recreational and eco-tourism • Contribute to Environmental Education and raising NBS awareness. |

The study recommends multi proposals for green infrastructures; preserving wildlife and grassland, adding new green spaces, vegetation, non-edible plants, shading trees and creating new open spaces and an ecological park that can protect wildlife and biodiversity. The initiative proposal demonstrates best practices, that aim to develop selected segments of the wadi that adopt a natural blue-green approach.

In addition, the proposed NBS' objectives support the socio-cultural values. Where the attached schools, institutes, universities and experts can play a societal role in educating and raising ecosystems and eco-landscape awareness.

The proposed eco-landscape adopts sustainable practices and management, such as encouraging the brown landscape rather than the green ones to suit the arid conditions. It supports the protection of wildlife, native plants, animals and other natural features of the site. It appraises the reuse and up-cycle of existing garbage, mainly construction wastes, in hardscape and landscape furniture, and it also amplifies the socioeconomic impact of building youth capacity, training and hiring the local labourers in eco-wastewater treatment. This approach intends to reconnect the citizens with nature, encourage walkability and positive actions. It also inspires laypeople by working with ecological and multidisciplinary scientists. The participatory design process extends to raising nature-based awareness through socialization and outdoor activities. The previously proposed approach asserts the potential of integrating NBS within eco-landscape practices, as it can mitigate air pollution, noise and heat islands by providing outdoor recreational and educational spaces. Moreover, the connection with nature won't only affect physical health and wellbeing, but it will also increase mental wellbeing and creativity. It is an emerging paradigm oriented mainly towards ecosystem services that would work better with collaborative practice and bottom-up actions with the acceptance of formal institutional counterparts.

We advocate that to strengthen the ability of the protected area to perform this 'new' function of restoring the watershed and reduce flooding risk, It also needs to be reconnected to the wider landscape to improve the entire watershed's functionality, and to upscale the project through connected corridors, spaces and streams, and by adding more green places to the city.

We argue that the use of all these potentials within this integrative NBS of eco-landscape approach would reduce environmental risks and face the current post-pandemic health issues as well as the socio-economic crisis. These in turn would effectively maximize urban resilience and meet the sustainable development goals (SDGs). However, there is a severe lack of practising NBS on both professional and policy-making levels in the real-world. Therefore, the paper recommends a gradual process to allow more time for assessment and refinement, as the continuous evaluation shall guarantee more improvements in a real context. Especially that the emerging NBS still needs to be widely applied and evaluated in Egypt.

This paper sends a message to lighten away towards more research on the restoration and naturalization of dry wadis in Egypt. Yet, the funding source is still one of the major obstacles to implementing such projects. We argue that if the restoration of dry wadis proposal is widely shared and discussed, and public contribution is encouraged; the process will continuously be developed, voluntary actions be facilitated and more support and resources be explored.

ABBREVIATIONS

NBS: Nature-Based Solutions

GTRS: Grey-water treatment and reuse systems NGO: Non-governmental organization

NRIAG: The National Research Institute of Astronomy and Geophysics in Helwan

ACKNOWLEDGMENT

The author would like to thank Eng. Asmaa El- Mekkawy, NRIAG's researcher and Bena'a foundation, for sharing their knowledge in the participatory divergent dialogues that are conducted by the author, at a margin of a workshop studying the feasibility of executing an eco-park on a segment of North Abu-Silli dry wadi, in Helwan. Special thanks to Dr. Ashraf Kotb and his survey-laser scan team for providing us with the contour maps.

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A PARADIGM SHIFT IN UTILIZING RESIDENTIAL ROOFTOPS AS SEMI-PUBLIC SPACES IN CAIRO DURING COVID-19 ERA

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ABSTRACT

The world is facing an increasing urban population living in urban areas, with significant decrease in public spaces, especially in megacities. Moreover, in the last couple of years, pandemic and Covid virus became a burden to access open spaces and outdoor areas, which need an emergent respond. In the light of the New Normal, new innovative approaches are currently taking place as a scheme for reforming private and semi-public spaces such as rooftops reactivation, balconies reuse, regenerating leftover space, and terraces repurpose. Therefore, this paper discusses the paradigm shift in utilizing rooftops as innovative approaches as semi-public spaces in high-density environments, which acts as another option for activities in the Covid-19 era.

The paper methodology depends on three main phases: (1) the theoretical phase that identifies the research problem, definitions, and the research framework; (2) the analytical phase that focuses on the global practices; and (3) the empirical phase that focuses on Cairo city in Egypt. The empirical phase is conducted through using questionnaire for the inhabitants and the experts in this field, in order to assess the paradigm shift, and their preferences. Finally, the paper examines the applicability of reutilizing rooftops as a quick and effective semi-public space that can be adopted in megacities during the pandemic era, with special reference to Cairo in Egypt. Moreover the paper aims at filling the gap between the design and users' needs through the extracted guidelines from the theoretical and applied phases, which results in recommendations for designers.

KEYWORDS

New Normal, COVID-19, Semi-public Space, Rooftop Reactivation

INTRODUCTION

The United Nations (UN) stated that by 1950, 30 % of the world's population was considered as urban and by 2050, this percentage would be 66 % [1]. Concerning open spaces, there is an urgent need for more open spaces as they are declining in the increase of the built environment, in order to meet user's needs, due to the inefficient use of resources. Cities consume 50 % more natural resources than thirty years ago, which creates complex urban systems [2] [3]. As a result, the call for sustainable cities and spaces took place in achieving sustainability to be achieved by 2030, and meeting user's needs, through achieving safe and affordable public spaces, inclusive and sustainable urbanization [4]. [5]. Semi-public spaces act as the main source of enhancing interaction between users including city and neighbourhood streets, parks, squares and other shared spaces such as private gardens; in addition to enhancing good quality of life [6]. Therefore, this study aims to present the idea of reactivating and utilizing residential rooftops as an alternative semi-public space after the pandemic. To achieve the paper's aim, the authors intend to meet the following objectives:

- Reviewing the literature to identify different global and local practices.
- Analyzing the situation of Cairo residents' behaviour pre and post COVID-19 era.
- Adapting innovative approaches for semi-public spaces in high-density environments.
- Helping the designers to understand the users' needs to recommend proper guidelines. It will be presented through the research structure that includes research methodology, rooftops background, international and local practices, results, recommendations, and conclusion.

RESEARCH METHODOLOGY

The research presents the utilization of rooftops as semi-public spaces during the pandemic in Cairo, Egypt as the case study. The research methodology is divided into three phases: theoretical, analytical, and empirical. The research depends on a mixed-method approach of quantitative and qualitative as shown in Figure 1. First, the study is inductive as it focuses on utilizing rooftops observation locally in Cairo and internationally all over the world. In addition to this, the study investigates and analyses people and experts' different perceptions and opinions, in order to develop recommendations and guidelines for using the rooftops, concerning the design, types of activities, construction, and governmental restrictions. While the quantitative method (online and offline survey) focuses on getting a representation of the current situation, with statistics in the real world (objectivity) [7]. The online survey was distributed via social media by using a random sample, as it is faster and cost-effective, in addition to other online platforms that can be a valuable research as some of them has 49 940 000 users in 2020 in Egypt that represents 47.8% of its entire population [8]. The researchers are aiming to get 383 surveys to represent a representable sample of the population of Cairo. However, only a sample of 73 respondents was used as a guiding reference in the study.

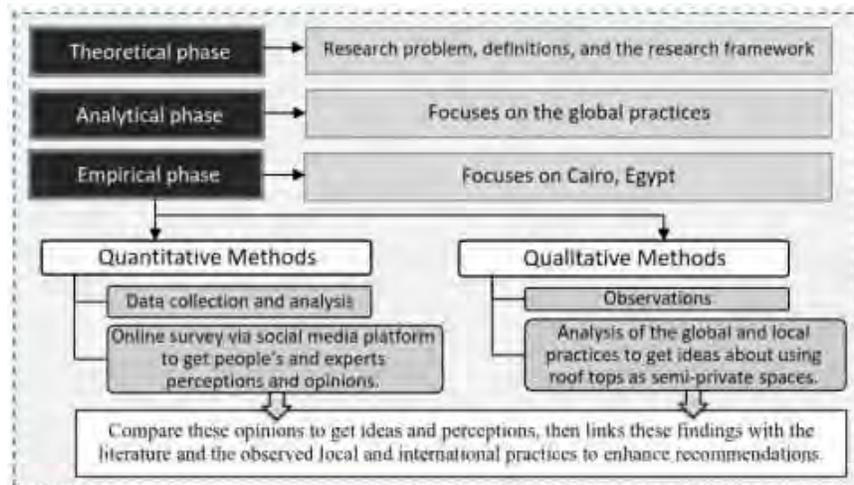


Figure 1 A Chart Illustrating the Research Methodology.
Source: The Authors THE SIGNIFICANCE OF ROOFTOPS DURING COVID-19 ERA

Understanding and improving urban spaces have become an inevitable part of planning cities in the 21st century. Generally, the regulated open spaces ‘Semi-Public’ include education campuses, schoolyards, neighbourhoods/community parks/gardens, residential gardens, national parks, and institutional grounds. Besides, residential rooftops, incidental spaces, and pocket parks are considered as other important forms of semi-public open spaces performing similar functions. While the public open spaces contain land, water- courses, or other landscape elements include public parks, public playgrounds, public sitting areas, public plazas, public piazzas, urban squares, or other natural areas. The COVID-19 pandemic has affected every level and scale, including individuals, communities, organizations, governments, housing, workplaces, neighbourhoods, and public spaces. This research focuses on the potential of creating a multi-layered city through the activation of residential rooftops in the light of COVID.

Peoples’ desire for Connection

On 11 March 2020, COVID-19 has officially declared a pandemic by the World Health Organisation (WHO). After the outbreak, half of the world lived under lockdown at several periods to curb the spread of the virus and loss of lives. Several cities-imposed restrictions on citizens’ mobility, asking them to stay at home and avoid many public places that turned off most of the urban living benefits. As a response to the pandemic, technology offered the option to connect virtually/remotely with the external world while maintaining social distancing (i.e., retail, shopping, banking, higher education, etc.). Thus, this directs people more towards passive engagement that involves meeting their need for encounter without becoming directly involved or as called active engagement. This paradigm is called the new normal which involves many new realities (i.e., social, and psychological). It became a dominant intellectual terminology among architects and urban planners. Beyond mere shelter, homes have begun to acquire a variety of roles, including workplace, school, gym, restaurant, laundry, and theatre. This has made their utility and designs even more vitally important [9].

Accordingly, negative consequences gradually appeared including loneliness, anxiety, reduced productivity, unhealthy sleeping and eating habits, potential obesity, and loss of various benefits associated with reduced human-human and human-environment interactions [10]. Physical isolation and the low-income living conditions with the absence of appropriate open spaces are some of the main causes of discomfort, depression, and mental health illness. Mental health is a critical issue that needs to be fought through pandemics and many factors including not being able to get fresh air and light, no physical movement or exercise, and isolation [11].

As a corollary, peoples’ need to go outside has been so important than ever before. Moreover, the COVID-19 pandemic made people realize the value of reachable open spaces that allow movement, especially within dense urban areas. As a practical response, many dwellers have the Going Out by Going Up approach towards utilizing rooftops in different cities globally as a new layer of urban open space. Building rooftops become preferred places for dwellers at this time (whether they are green or grey) as a refuge from the lockdown daily routine, and the bustling city, in addition to enhancing the interaction through creating places that promote happiness [12].

“During the lockdown, city dwellers went out on rooftops, not only to get some exercise in the fresh air, which seemed to be the most favoured rooftop activity, but also to work, make calls, fly a kite or a drone, dance, read a book, play an instrument, make art, drink *coffee*, *do sunbathing or gardening*, *have socially distant conversations with theirneigh- bours*, or *wave to neighbours from next roofs*,” *Monika Hankova* - [13]

Rooftops Reactivation

There are common roof types classified into low/no slope roof (flat roof) and sloped roofs (i.e., gable roof, clipped gable roof, Dutch gable roof, gambrel roof, hip roof, mansard roof, shed roof). The typical flat roofs are the best place for the dwelling extension that can provide much needed private or semi-public exterior space for urban housings [14]. Before the Covid-19 breakout, people know that residential building flat rooftops are the place where the building services (i.e., HVAC equipment, solar panels, water tanks, etc.) usually locate or communal tenant spaces for mixed-use buildings (residential and commercial buildings). An estimated statistics revealed that rooftops represent 15-35% of cities’ total land area, thus considered exciting spatial resources. In denser urban environments, the idea of activating rooftops and underuse spaces as opportunities for further development are a new-found interest especially after Covid-19 outbreak [15] [16].

Throughout human history, every health crisis has taught us two main lessons (1) the importance of our ‘responses’ pre and post crisis, and (2) our ‘preparedness’ for related issues (i.e., building design, urban open spaces, social disconnection, waste disposal, sanitation issues, etc.) [17] [11]. In this vein, many questions are asked including the ideas performed to reactivate the rooftop. Does the residential rooftops are ready for the different types of activities/amenities? Are the rooftops ready for more foot traffic? What are the barriers the residents faced reactivating their rooftops? What is their viability in the future (post-pandemic)?

Handling the new paradigm shift towards rooftops

It is still uncertain whether it will be possible to return to the normal pre-pandemic life-style, and this shows that pandemics, wars, and disasters are a concrete part of life. Therefore, cities should determine lifestyle trends, problems, needs, and the suitability of residential environments during the COVID-19 pandemic [18]. Concerning cities preparedness, building owners, Architects and urban designers should seek appropriate solutions for improving the current scenario and leverage the potentials exist.

INTERNATIONAL PRACTICES

COVID-19 Era has made it clear that people who do not have access to green spaces should view greenery or grow plants in their houses. People's need for fresh air in cities has increased which emphasized the need of balconies and patios. Rooftops in many cities in Europe, Asia, and the Arab world neighbourhoods have become spaces for safe social-ization, musical communication and supporting people's solidarity [18]. Rooftops reacti- vation in residential buildings has been shown in many places in the international context in the Covid Era as shown in Table I. As many places became closed and outdoor activi- ties are restricted, people started to come up with new ideas as shown in Table I. It has been shown that one of the important issues in the disease spread is the inequalities, as most of the low-income households in India as an example do not have hand-washing facilities [19]. Low-income communities pay less attention to social distancing, and this is attributed to work conditions. The high-income workers can work remotely, which al- lows them to be more careful [20] [21]. Similarly, in densely populated spaces in the United States, Latino and Asian neighbourhoods are more vulnerable to economic diffi- culties and disease than White neighbourhoods due to residential segregation and con- centrated poverty [18]. The elderly were seen gathered for getting fresh air, while kids and youth started to use it for several activities, such as using it as a playground, gym, sport activity, praying zone, painting studio, concert hall, performing music, and urban gardens. Moreover, some people used rooftops for leisure facilities such as basketball courts, yoga place, gathering area, restaurants, mini golf, and pools.

Table I Presenting Global Practices In Utilizing Rooftops

| | | | | |
|---|---|---|--|---|
| Cinema, Greece | Sport, USA | Cafe, Auckland | Vaccine clinic | Concert, Spain |
|  |  |  |  |  |
| Source: Dimitris Bouras, 2021 | Source: usatoday.com | Source: stuff.co.nz | Source: healthline.com | Source: theworld.org |
| Festival, France | Concert, Germany | Eid Prayer, Bangladesh | Rooftop igloos, Durham | Performance, Germany |
|  |  |  |  |  |
| Source: france3- regions | Source: telegraphherald.com | Source: halamy.com | Source: dukechronicle.com | Source: indianexpress.com |
| Planting, Barcelona | Stretching training, Rome | Sitting Area, New York | Pools, Kessler, NYC | Gathering, Vene-zuela |
|  |  |  |  |  |
| Source: iied.org/ co vid-19-highlights | Source: weforum.org/agenda/2020 | Source: streeteasy.com | Source: streeteasy.com | Source: weforum.org/agenda/2020 |

Source: The Authors Based On References, Retrieved In November 2021 LOCAL PRACTICES

Concerning Egypt, many buildings' rooftops aren't ready to accommodate. On the other hand, some private rooftops became in high demand after Covid for making activities and residents started to improve their roofs. In Cairo, some initiatives started to take place in utilizing roofs after the pandemic as shown in Table II. As a result, inhabitant and initiatives started to plant the roofs and made small productive urban farms, as the amount of green and open space per inhabitant is 0.33 m² per person, which is one of the lowest percentages around the world [22]. In addition to this, some roofs became an open gym and sports area. Moreover, many start-ups and initiatives have arisen focusing into rede-signing rooftops to be suitable for putting tables, stage, lighting units, seats, and sheds for ceremonies such as engagements and birthdays. On the other hand, some residents could not use their roofs in Cairo due to some burdens including the inaccessibility of their roofs, design structure isn't ready for the added load of people, neglected roofs are used for collecting garbage and lack basic amenities. However, some new approaches tried to overcome those burdens by adding insulating sheets and cleaning those roofs, in addition to redesigning it and adding furniture. Moreover, in some informal areas it has been said that "We don't have the space to plant trees, but we have 500,000 rooftops" by one of Shadouf initiative participant [23]. The research discusses in the next section the results and discussion, where a questionnaire was held on a sample group in Cairo, to investigate the current situation and recommend some guidelines to improve roof utilization.

Table II Presenting Local Practices Of Utilizing Rooftops In Cairo

| | | | | |
|---|---|---|--|---|
| Working Space, Dokki | Cermony/Wedding, Giza | Cafe, Cairo Downtown | Living area, Old Cairo | Birthdays |
|  |  |  |  |  |
| Source: facebook.com/MajalSpace | Source: facebook.com/amany.flowry | Source: facebook.com/ElBosat | Source: Taha Abeer, 2021 | Source: facebook.com/amany.flowry |
| Study Area | Gathering node | Concert | Swimming pool | Playground |
|  |  |  |  |  |
| Source: https://www.facebook.com | Source: Alaa ELdin , 2021 | Source: https://www.facebook.com/DowntownCairo | Source: https://www.youtube.com | Source: https://www.youm7.com |
| Workshop and studio, Shoubra | Productive Landscape | Planting | Roof before improvements | Painting Workshop |
|  |  |  |  |  |
| Source: https://www.facebook.com/RecyclingForArchitecture | Source: facebook.com/shagrha | Source: facebook.com/Elfaslaonline | Source: Khaled Desouki, 2014 | Source: www.aucegypt.edu |

Source: The Authors Based On References, Retrieved In November 2021

RESULTS AND DISCUSSION

This study discusses the paradigm shift in utilizing rooftops as innovative approaches as semi-public spaces in high-density environments, which acts as an alternative for activities in this era. The researchers use (quantitative methods) questionnaire for the inhabitants and the experts in this field to reach this aim. The survey is composed of four main sections, which established some basic demographic information, the residents' previous experiences before & after Covid, their preferences, and the experts' opinions.

Questionnaire: Section A: Demographic Information:

72 respondents are reported where most of the respondents are females (79.17%) and males (20.83%). Among the respondents, the age between 25 and 34 years old (59.72%) are found to be more than other age groups, followed by age between 18 and 24 (12.5%), age 45-55 (11.11%), over 55 (9.72%) and 35-44 (6.94%). Survey finding shows that most of the respondents had bachelor's degree (58.33%) followed by MSc. degree (37.5%) and finally PHD degree (4.17%). In terms of their current employment status, the majority are full time employed (52.78%), followed by part-timers (15.28%), unemployed (do not search for a job) (12.5%), unemployed (search for a job) (8.33%), retired (5.56%), student (2.78%), and self-employed (2.78%). In addition, it was significant to ask if they are experts in the architectural, construction, or planning field or not. The respondents are divided between experts and non-experts, but the experts are more with 59.73%. Furthermore, collecting data about their place of living was essential and the period they lived in this place. Therefore, they are asked if they own or rent their residential units, most of them own their apartments (77.78%), 15.28% rent, and only 6.94% shared, in addition to asking about the households number as shown in Table III .

Table III Presenting Demographic Information About The Sample

| How long have you lived in this area? | | | | | | | |
|--|--------|-------------|--------|-------------------|--------|----------------|--------|
| < 1 year | 4.17% | 1-2 years | 8.33% | 2-5 years | 18.06% | | |
| 6-10 years | 13.89% | > 10 years. | 54.17% | No answer | 1.39% | | |
| How many kids do you have? | | | | | | | |
| No Kids | 59.72% | 1 kid | 9.72% | 2 kids | 13.89% | 3 kids or more | 16.67% |
| How many persons live in your home including children? (Please count yourself) | | | | | | | |
| 2 persons | 13.89% | 3 persons | 15.28% | 4 persons | 29.17% | 1 person | 2.78% |
| 5 persons | 20.83% | 6 persons | 11.11% | 7 persons or more | 5.56% | No answer | 1.39% |

Source: The Authors

Questionnaire: Section B: Behaviour Information (Pre and post Covid 1 activities)

The respondents are asked about their activities and usage of roof tops pre and post Covid aiming to study the differences in people's behaviours.

Pre Covid

The study identified that most of the respondents did not use the roof of the building before to do any kinds of activities before COVID-19 (80.56%) and only 19.44% used it before. On the one hand, the reasons behind not using it are numerous, 43.06% from the sample did not mention the reason behind do not using it, 25% did not think about it, 18.06% did not need to use it, and 12.50% prefer going outside the home. On the other hand, respondents who used it before clarified the kind of activities that they used to do on the roof before Covid-19 and how often they used it, as shown in Table IV:

Table IV Presenting Behaviour Information Pre Covid

| If yes, what kind of activities you used to do on the roof? | | | | | | | |
|---|--------|-------------|--------|------------|-------|--------------|---------|
| Gathering area | 15.28% | Gym | 1.39% | pool | 0% | Other | 83.34 % |
| How often do you use the roof? | | | | | | | |
| Each day | 6.94% | Twice /week | 0% | Once/ week | 0% | Twice/mont h | 0% |
| Once/month | 2.78% | Rarely | 30.56% | Do not use | 59.7% | | |

Source: The Authors

Post Covid

The same questions are investigated but post Covid-19 as shown in Table V. The study clarified that most of the respondents did not use the roof to do any kinds of activities post COVID (76.36%), and only 16.67% used it, and 6.95% did not answer. On the one hand, the reasons behind not using it are numerous, 41.67% from the sample answered that they did not think about it, 45.84% did not give a reason, 8.33% did not have money or financial support to renovate it, 4.17% are scared to meet other people and spread the virus. However, respondents who used it before clarified the kind of activities that they used to do on the roof post Covid-19 and how often they used it.

Table V Presenting Behaviour Information Post Covid

| If yes, what kind of activities you used to do on the roof? | | | | | | | |
|---|-------|-------------|--------|---------------|--------|---------------|--------|
| Gathering area | 25% | Gym | 1.39% | Swimming pool | 0% | Other | 73.61% |
| How often do you use the roof? | | | | | | | |
| Each day | 8.33% | Twice /week | 0% | Once / week | 0% | Twice / month | 0% |
| Once/month | 1.39% | Rarely | 33.33% | Do not use | 43.05% | | |

Source: The Authors

Questionnaire: Section C: Preferences:

The researchers aimed to understand better the main features or strengths that facilitate the use of the roof and the main difficulties that prevented the residents from using it. Therefore, the respondents are asked first about the strengths in an open question. Their answers are various; they are summarized in these points:

1. A large area is more than the size of the house, and there is air and sun,
2. Residents can enjoy the view and the skyline,
3. High privacy area,
4. A place where children play as an alternative to the garden,
5. A place used as a shelter for the neighbours' dogs,
6. Possibility of gathering while maintaining distance, and
7. Isolation from crowds and open space.

Furthermore, if they did not use it, they are asked what issues or difficulties prevented them from using it? Their answers are reported in Table VI:

Table VI Presenting Preferences Of Users Regarding Rooftop Usage

| | | | |
|--|--------|---|--------|
| Lack of financial support | 6.94% | Scared of Covid | 1.39% |
| Scared of doing something which effect the construction of the building | 0% | Cannot get permission from the building' owner (if rent) | 12.5% |
| Did not have ideas of good activities | 19.44% | Other | 40.27% |

Source: The Authors

Furthermore, people mentioned some additional points which prevented them from using the roof, such as:

1. The roof is privately owned, and not all the residents can use it,
2. One of the residents did not want some of the owners to take advantage of the roof, the difficulty of agreeing with the neighbours,
3. It is impossible to use the surface due to the presence of tanks and systems for the buildings, as they are buildings with a cluster system,
4. The ceiling is closed, and access to a wooden ladder is challenging to climb, and the place is unpaved,
5. Sometimes, the ladder to reach the brightness is vertical, and many people cannot use it because it is not an ordinary ladder,
6. The building owners use the roof to raise birds and animals, and we could not use it before or after Covid, and
7. People could not think of using the roof for safety and security issues. In addition, the surface has no ownership; clearly, it was difficult to manage.

Questionnaire: Section D: Experts' opinions:

In this part, the experts (36 participants) are asked some specific questions related to the architectural and construction field. First, the researchers wanted to investigate if due to Covid, do we need a new typology for public space or not? So, 88.9% of the experts mentioned the significance of new type of open spaces while 11.1% reported that there is no need to these spaces. In addition, they justified their answers by some points as follows:

1. People's needs are different from before,
2. According to this type of change, the emergence of some requirements in life includes social distancing, adherence to masks, hygiene, and sterilization, and
3. All public places and parks need an entry ticket; there are no public places for residents to picnic without paying fees. In Egypt, we have a problem with the concept of public places by converting them into profitable consumer places, as they have all turned into gardens with walls or large squares with cafeterias and kiosks, and payment must be made to sit, as there are almost no public places.

Also, they are asked if the temporary transformations during the crisis inspire permanent changes or not? Therefore, 77.7% agreed with this statement while 22.3% did not agree and said no. Then, they mentioned the threats of reusing the roofs of the buildings as a public space for people to communicate, which could be summarized as follows:

1. Dangerous to the safety of children and people in general and extreme heat, especially in the absence of any sun visors,
2. Misuse of surfaces such as not feeling responsible, lack of maintenance,
3. The lack of knowledge of the construction conditions of the roof may cause problems for the facility,
4. Theft from the public may use and noise in the late hours,
5. The idea is successful if it is limited to the people of the house only,
6. Dangers associated with the control of some owners on the surface and the unwillingness to benefit everyone - closure Societal - risks arising from safety and security factors and low turnover,
7. In the case of adding loads that may affect the foundations of the building,
8. There are no more dangers than social problems, meaning that there must be a separate gathering of women and children and, another day, men, and youth, and
9. Some residents dispute over their ownership of the roof.

Additionally, the experts are asked about the significance of the residents' involvement in the design of their building roof and the main features that the engineer should consider when redesigning a roof for activities purposes. The experts' opinions as shown in the shown table, are divided equally between should be involved 25% and should be involved with expert help. We must mention that half of the experts answered, 'do not know' (50%) if the resident be involved or not. Maybe because of some safety factors. Furthermore, the experts highlighted the significance of some features as shown in Table VII that may influence the design of the activities. The features in descending order from the most important to the less are Residents' opinions, Construction restrictions and budget, types of activities, and the government restrictions due to Covid.

Table VII Presenting Experts' Opinions

| Do you see that residents of the building should be involved in redesigning their building roof or they should leave this to an expert or at least ask an expert for help? | | | | | |
|--|----------------------|--|---------|-----------|----------------|
| Should be involved | 25% | Should be involved with an expert help | 25% | | |
| Should not be involved | 0% | Do not Know | 50% | | |
| How important is each of the following features to you when redesigning a roof for activities? | | | | | |
| | Importance to you | | | | |
| | Not important at all | Not important | Neutral | Important | Very important |
| The budget | 0% | 0% | 27.03% | 27.02% | 45.95% |
| Type of activities | 5.59% | 0% | 25% | 41.67% | 27.78% |
| Construction restrictions | 0% | 8.33% | 19.44% | 16.67% | 55.56% |
| The government restrictions | 20.56% | 14.71% | 29.41% | 26.47% | 8.82% |
| Residents' opinions | 5.56% | 0% | 13.89% | 33.33% | 47.22% |

Source: The Authors

RECOMMENDATIONS

Issues of design, structure and accessibility are critical in rooftop upgrading. Since there is an evidence of more frequent rooftop use during COVID-19 quarantine, increased foot traffic should be considered. Considerations and strategies for utilizing residential rooftops should be divided for the re-development and new construction in the future. The roof should be designed to manage heavy loads and protects the roof assembly from increased foot traffic during its usage or upgrading as a communal space. Furthermore, the residents should be involved in the design and the selection of the activities, but it will be safer to be supervised by an expert. The budget is sometimes an issue or challenge if some of the residents do not want to participate. Therefore, a yearly budget should be collected from all the residents for the maintenance of these activities.

CONCLUSION

As the pandemic underlined a severe need for more outdoor areas, rooftops are regarded as a viable addition to the public space. New Approaches are taking place after the Covid Era concerning open and semi public spaces, in order to reform private spaces such as rooftops reactivation, balconies reuse, regenerating leftover space, and terraces repurpose. As shown in the analytical study the research concludes that there is a mutual relation between the built environment (urban context) and the concept of regenerating spaces based on users' needs. Therefore, there is an urgent need for designers to rethink rooftops of residential buildings, especially in neighbourhoods in megacities.

At a broader level, this paper contributes to the real world practices by presenting and analyzing different ideas for the residents and stakeholders helping them to reactivate their rooftops. A further applicability of this research study is making new prototypes for residential buildings and their rooftops, which can be multipurpose places for activities. Moreover, it is highly recommended to implement some interventions with the suggested guidelines to enhance rooftop utilization in the chosen case studies.

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ACTIVATING GREEN SPACES: RETHINKING POTENTIALITIES OF STREET MEDIANS AS CONTEMPORARY USABLE PUBLIC PLACES

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ABSTRACT

The rapid urbanization in Cairo has resulted in the provision and distribution of green space becoming very challenging. The need for more green space appears in huge crowds gathering in parks and green spaces during feasts and holidays. Public green spaces are either non-used or misused. People living in very dense areas on the urban periphery use some street medians as public parks. Those scattered islands represent an opportunity to create usable green spaces, accessible by diverse user groups to compensate for low provision. This paper investigates the different activities which take place in leftover urban spaces, especially street medians. It addresses the problem of spontaneous adaptations within the practiced activities in such spaces. Those adaptations vary based on different social levels. The paper aims to investigate how leftover spaces could be used as small community green spaces inside the dense city structure. The research examines medians' morphological, perceptual, functional, social, and temporal dimensions as public green spaces in cities. The aim is to highlight the potential of leftover urban spaces in enhancing the livability of cities and modern society. The presented study follows a methodology that consists of two parts. First, a literature review of theories and frameworks of urban open spaces, the different activities, and practices in urban spaces to extract the dimensions to be analyzed. Second, case study analysis for selected spaces in Greater Cairo, Egypt, which are visited and analyzed through visual analysis and behavior observations. Results reveal important outcomes including reasons and preferences of users for such spaces, landscape physical features, and street furniture which influence the efficient use of such spaces. The research suggests various recommendations for maximizing the benefits and efficiency of left-over spaces through possible activation of assets of public space to enhance the quality of life in congested urban contexts.

KEYWORDS

Median spaces, Green spaces, Urban environment, Public realm, Quality of Life

INTRODUCTION

The research aims to shed light on the importance of “Median Spaces” in congested city cores. Those spaces, sometimes regarded as leftover spaces or neglected spaces, can potentially enhance the city’s quality of life. The presented study follows a methodology that consists of two parts as demonstrated in the figure below (Figure 1). First, the literature review covers the previous debates on the matter, in regards to definitions, dimensions, characteristics, and the quality of life associated with enhanced design street medians as public spaces. Second, case study analysis for selected spaces in Greater Cairo, Egypt, which are visited and analyzed through visual analysis and behavior observations. The research methodology depends on an inductive approach based on a field survey. The research concludes with criteria that can be used to improve the use of street medians in the Greater Cairo Region as a dense context.

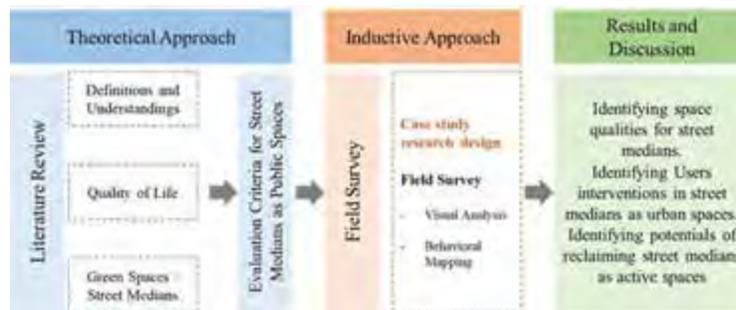


Figure 1. Research Structure Green Space Provision and Quality of Life

Several scholars have associated green space efficiency with the quality of life. Debates in this realm relate to the possibility of enhancing the ecosystems (1), health, and well-being of communities (2). Additionally, green spaces contribute to the social life of communities (3) through positive impacts on social inclusion, social justice, and cultural links between citizens via engagement in activities and outdoor public events. The quality of life can be categorized into six main aspects (4); physical well-being, environmental well-being, psychological well-being, social relations, level of independence, and spiritual well-being. All those categories are dominant in the positive effect green spaces have on individuals in case they are accessible, effectively designed, and well-maintained.

Some of these activities are incubated in quality green spaces (4) like; observing nature, socializing, relaxing, and sporting activities. These activities strongly depend on resources such as green spaces. Also, as argued by Manlun (2003), several users from middle- and low- income classes in various geographically located countries use parks and public gardens as spaces for socializing, relaxing, exercising, and enjoying the natural environment. However, the perception of the quality of life as an impact of green space provision has been more observed in low-income groups (5). The linkages between green space and quality of life associate human well-being with social and economic stability, where the natural environment affects them and is affected by ecosystem stability and wellness.

The Challenge of Green Space Provision in Cairo (Standards Vs Reality)

It is important in this study to shed light on the current state of green space in Cairo, focusing on street medians as green spaces which are the main case study for the fieldwork. Although Egypt’s National Organization for Urban Harmony [167] suggests 10m² of open spaces/inhabitants on the city scale, the reality is that public green spaces in Cairo suffer from deterioration and are being neglected. It is common to witness spaces that are fenced, inaccessible and privatized. The area of green space per person in Cairo is very small compared to other cities, to the extent that it reaches 0.5m² in some areas, which is very little in comparison to many other countries. This deprivation appears in the huge crowds in parks, green spaces, and street medians during feasts and holidays, which also reveals how much people need such spaces. It can be observed that most of Cairo’s public spaces behold Wilkinson’s eight weaknesses of public space, being inflexible, ignoring the needs of people’s behaviors, are not included for children, the elderly, and the disabled, do not enhance participation. Finally, unresponsive to changes in populations, residential densities, and recreation trends over time (6). It has been evidenced that open public spaces are not usually relevant where density is concerned: the allocation of open spaces for public use and shared social life is never taken into account as a parameter to express what a dense city is like or should be like (7).

The sprawl of road networks and the evolution of their types have gradually created new categories of mobility-related public open spaces which, despite their often-small size and residual nature, collectively can play a significant role in implementing a more sustainable built environment, vibrant connections, and biodiversity in urban habitats. To build more livable and attractive cities, the natural components, the cultural and social potential of public space systems should be interpreted in an integrated way at the urban landscape scale, including residual spaces generated by the construction of roads and intersections. This is very dominant in the case of Cairo due to the over-urbanization and the lack of the dominance of public space in planning.

Dealing with different parts of the urban realm as isolated objects, rather than as part of a larger urban system has brought pores of vacant and underused lands in the urban core. It can be observed that “*these lost spaces and the broken connectivity are symptomatic of an ill-shaped and ill-planned urban environment.*” [14]. If we look at what brought people to other public parks, the answer is the availability of common interests that can attract diverse social groups with unified interests, one example is the annual spring flower fair that takes place in Orman garden, at that time of the year people from all places and social classes visit the garden at the same time, some sports group even organized a bike ride for the exhibition.

Definitions and features of greenspace analysis

In this part, some relevant definitions to the course of the study would be highlighted (8) which will help in the selection of the local case studies, based on their relevance. The relevant definitions are summarized in the table below (Table 1). Those definitions will help in the tailoring of the observations, as well as tracking the activities by mapping them in the selected local case studies.

Table 1. Important Definitions from Previous Literature, (Compiled by Authors, 2021)

| | | |
|---------------------------------|---|--|
| Trancik (1986), (9) | Lost spaces | “The unwanted areas in the urban settings which require redesign, and anti-spaces, with no positive contribution to the surroundings or users.” |
| Urban Task Force, (10) | “SLOAP” “Space Leftover after Planning” | “Soulless, undefined places, poorly landscaped, with no relationship to surrounding buildings.” |
| Loukaitou-Sideris, (1996), (11) | Neglected Spaces | “Residual, littered, unmaintained, and prone to urban decay spaces.” |
| Winterbottom (2000), (12) | Residual Spaces | “Non-spaces,” “leftover spaces” and “dual-use spaces”, include median strips and rights-of-way along highways and roads. |
| Rivlin, (2007), (13) | Found spaces | “Found spaces are generally located in convenient places that take little time and effort to reach, visible and accessible enough to draw people’s attention to them.” |
| Frank and Stevens, (2007), (14) | Loose spaces | “Those are spaces subject to appropriation and freedom of choice, whether they are originally designed or abandoned.” |
| Rahmann & Jonas (2011), (15) | Urban in-between spaces | Urban spaces could be used to bring together “disparate activities and character in a manner that creates valuable exchanges and connections”. |
| Dall’Ara et al. (2019), (16) | Residential medians | Residual space at the smallest scale. As “non-spaces,” they may not be read in the landscape at all or might be seen as sites for illegal parking. |

The Criteria of evaluation that are relevant to the course of analysis can be summarized as shown in the next part. The “green space” needed to be activated in cities, especially congested cities like Cairo, should include spaces for everyone. Additionally, those spaces need to be safe, welcoming, well maintained, and managed. Also, it is crucially important to incubate a specific function to enhance social as well as economic sustainability. ‘Fitness for purpose’, by definition, requires the assessment of green-space quality to reflect the intended purpose or need. Green space is often multi-functional, which is one of its great strengths and quality attributes (17).

Green spaces of quality are required to be evaluated on the local and regional levels. While indicators vary, they target play spaces for local communities on the local scale, and corridors of movement and connected networks on the regional level. In addition to more national aspects, like the impact of climate change. The benefits of green spaces can be either direct or indirect. Direct benefits include the provision of play, access, biodiversity, safe routes to school, recreation, and many others. Indirect benefits include social change and the promotion of more sustainable lifestyles, such as reducing car dependency, supporting healthier lifestyles, and facilitating more active communities, (17).

Finally, the criteria of the analysis concluded from the previous literature review regarding the nature of successful public green space, which would be applied in selected case studies, are shown in the figure below (Figure 2).

| Evolving | Inclusive | Engaging | Balanced | Comfortable | Distinct |
|--|--|-----------------------------|---|--|--------------------------------|
| Allows growth, flexible to adapt to un- assigned activities. | Avoiding non-tailored designs that are not adequate for different users. | Promotes social engagement. | Balances between traffic and pedestrians. | Physically comfortable, safe and relaxing. | Encompasses explicit features. |

Figure 2. Criteria of Evaluation of Street Medians Selected Cases. (Authors, 2021)

CASE STUDIES

The case study methodology is selected for the presented study (18). It investigates the different patterns and types of activities that take place in street medians in two major streets selected in the greater Cairo Region. The study investigates the relationship between space qualities and users' interventions and activities in the two selected street medians to understand how street medians could serve as community spaces. This investigation can help in developing better options to maximize the benefits of the available green spaces in high- density urban areas.

Selected case studies

The two selected streets in Greater Cairo Region (GCR)-Egypt represent vital connectors, and important land uses (commercial and recreational), and can be easily accessed through public transportation and private cars. They are also important attraction points to residents of the Greater Cairo Region (GCR). The selected streets are Gameat El-dewal Al Arabiya Street in Mohandessin district and Nahdet Misr Street. Figure 3 shows the location of the selected street medians.



Figure 3. The selected case studies in Cairo's Context

Gameat Al Dewal Al Arabeya Street lies in Mohandessin district, Giza. It starts from Sudan Street in the east to Sphinx Square in the west, with a length of 23 thousand meters, and extends from the Agouza area in the Sphinx through the Mohandessin area to Sudan Street. It is an exceptional street and is considered a prominent landmark among the streets of Egypt as it is a permanent refuge for most Arab tourists who prefer to live and walk in it. Also, it is characterized by its richness in activities and land uses, cafes, restaurants, and administrative buildings are found there. Thus, it is a vital artery in Mohandessin area.

Nahdet Misr Street runs through the heart of Giza, comprising two of the most prominent landmarks: Nahdet Misr Statue and Cairo University. Both represent an important phase in the history of modern Egypt regarding art and education. The name Nahdet Misr means Egypt's renaissance. The street is named after the famous Nahdet Misr statue sculpted by Mahmoud Mokhtar, a pioneer of modern Egyptian sculpture. Walking forward, leaving the statue behind, the tree-lined street is surrounded by the fence of Giza Zoo and Orman botanical garden, both were implemented on the order of Khedive Ismail.

Data collection

A field survey was conducted to document the main physical features of both streets and to record the different patterns of activities that usually take place in their street medians. The survey was conducted using base maps, map annotations, and photographs. Details of both streets were recorded showing space structure and different land-uses which have a great impact on the existing activities. Behavioral mapping was conducted to show activity distribution along the street medians and was recorded on base maps to highlight its relationship with current land uses and commercial or recreational activities in both streets. Site visits were conducted starting from the 25th of October 2021 till the 10th of December 2021. Both street medians were visited the same number of visits on random weekdays and weekends.

Data analysis

To understand the relevance between the urban qualities and criteria of selected medians and the existing interventions; urban qualities and activities concurrences were rated during the site visits done by the researchers. Activity maps were established to help in locating, recording, and counting different activities and rating different qualities in both spaces during weekdays and weekends, in day and night time intervals.

Physical features

The different features in both street medians are documented to better understand space qualities and different users' interventions and activities in both streets. Landscape elements in both the two street medians are shown in Figures (5,6,7,8).

Gameat Al-Dewal Al-Arabiya Street median is rich in soft-scape features of living trees, shrubs, and palms. Moreover, hardscape elements are in a good condition and offer different space varieties for people, like pergolas and benches. Nahdet Misr street median is also rich in soft- scape and hard-scape elements. It is famous for the statue of Nahdet Misr which is a major landmark and the fountain which looks very special at night due to the light effects added to it. The survey showed that the quality of green areas in Gameat Al dewal Al-Arabiya is better than the quality of green areas in Nahdet Misr Street median.



Figure 4. Softscape elements in Gameat Al-Dewal Al-Arabiya Street median



Figure 5. Hardscape elements in Gameat Al-Dewal Al-Arabiya Street median

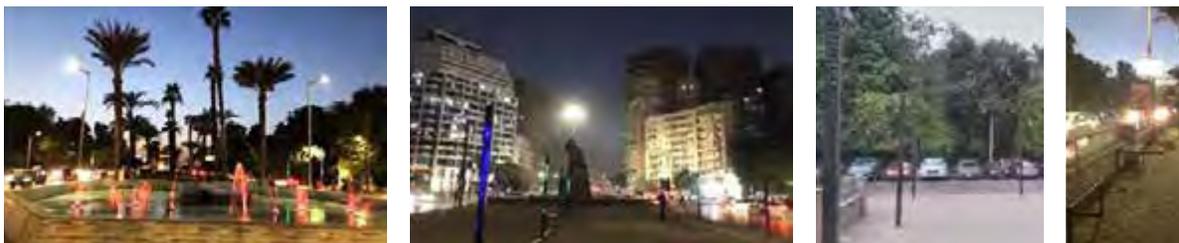


Figure 6. Hardscape elements in Nahdet Misr Street median space



Figure 7. Softscape elements in Nahdet Misr Street median Behavioral mapping

The main objective of the behavioral mapping is to identify the different patterns of activities and different uses in the selected street medians, and how people perceive such an urban environment. Along with the different qualities in these spaces. Conducted observations confirmed that both streets have rich social experiences, due to the variety of activities in them. Figures (8&9) show the behavioral mapping of different users' activities and interventions in Gameat Al-Dewal Al-Arabiya Street median. The presented mapping shows users' activities at both day and night intervals. On Thursday which is considered the start of the weekend, the observation showed that during the day and due to work and weather conditions fewer activities occur in the space. Only activities including sitting in shaded areas take place and most of the users either socialize or try to have some rest after a long day of shopping or a long trip. At night more activities take place since people are getting ready for the weekend so they enjoy their time after visiting restaurants and shops along the street.



Figure 8. Behavioral mapping for activities in Gameat Al-Dewal Al-Arabiya Street median



Figure 9. Activities - in Gameat Al-Dewal Al-Arabiya street median

Nahdet Misr street median showed a medium density of activities during the day due to the existence of Cairo university students, and Giza Zoo visitors; however, more activities took place during the night. During the weekend youth gather inside the green area in the street median more than on weekdays, they enjoy sitting and sleeping on the grass. Also, children play around the fountain, and many users enjoy taking photos with the Nahdet Misr statue, a famous landmark. Moreover, some user groups used to celebrate open-air weddings on Thursdays near the Nahdet Misr statue and fountain, others use it as a place for picnics. The setting is very active at night, it showed significant vitality during the whole week due to the surrounding land uses as shown in Figures (10&11).



Figure 10. Behavioral mapping for activities in Nahdet Misr Street median



Figure 11. Activities in Nahdet Misr Street median

RESULTS

This section presents the results of analyzing the collected data. The conducted survey confirmed that street medians' design plays an important role in adopting different users' activities. In addition to the richness of space elements and components which offer different types of activities.

Qualities and potentials of selected median spaces

Both street medians show qualities which contributed to users' interventions and their activities in the space. Table 2 shows the qualities and activities for Gameat Al-Dewal Al- Arabiya Street and Nahdet Misr Street.

Table 2. Qualities and Patterns of Activities (Compiled by Authors, 2021).

| Gameat Al-Dewal Al-Arabiya Street | | Nahdet Misr Street |
|--|--|--|
| Qualities of the space | | |
| Location | Giza – Dense downtown area | Giza – Connector to river Nile |
| Length | 964 meters | 508 meters |
| Land-uses | Commercial – Residential – Recreational | Educational – Recreational |
| Patterns of activities and users' interventions | | |
| Activities | Recreational – Vending – Walking – Sitting | Recreational – Vending – Walking |
| Users | External visitors – Locals Individuals – Groups | External visitors Individuals – Groups |
| Time and duration | Day (Low density) Night (High density) | Day (Low density) Night (High density) |
| Week | Weekdays (Low density) Weekends (High density) | Weekdays (High density) Weekends (High density) |

Regarding the characteristics of both street medians, it came up as follows. There are a variety of activities adapted by users in this street median which makes the space highly evolving, while the level of inclusion is low because the space does not offer a variety of activities for diverse user groups. Gameat Al-Dewal Al-Arabiya street median has high visibility, accessibility, and exposure, the street median elements are in a good condition with some interesting landscape features, leading to a medium level of engagement and robustness. Gameat Al-Dewal Al-Arabiya Street showed a high balance between traffic and pedestrian flow, but it requires some traffic management measures to promote pedestrian safety.

Observations should show that it offers a high sense of security and sense of comfort as a result of active commercial frontages, the good condition of the median elements, and human scale, while it offers a medium level of physical comfort due to the availability of some shaded areas and seats.

Activities taking place in Nahdet Misr Street median indicate a high level of evolution and a medium level of engagement. Nahdet Misr street median is highly accessible and the proximity to Cairo university resulted in a higher level of diversity of user groups than that found in Gameat Al-Dewal Al-Arabiya. Being in a distinctive location and the availability of distinctive features such as the statue and the fountain, give the space a special character and high level of robustness. These distinctive features promote more passive engagement possibilities.

Nahdet Misr Street showed a medium balance between traffic and pedestrian flow. Observations suggest that it offers high security and low physical comfort due to the lack of furniture like seats and shaded areas, however, it offers a medium sense of comfort due to the good condition of landscape elements and reasonable human scale.

Both spaces offer a high sense of joy and sharing as a result of the different interventions done by users, like celebrating special events (e.g. weddings, birthdays ...etc.) and offering some passive engaging features, in addition to street vendors who sell different products that attract users' attention.

These observations made it possible to use the deduced evaluation criteria (Figure 2) in interpreting the qualities of street medians in both case studies as shown in Table 3.

Table3. Criteria of evaluation of Street Medians (Compiled by Authors, 2021)

| Evaluation Criteria | Gameat Al Dewal Al Arabeya Street median | | | Nahdet Misr Street | | |
|---------------------|--|--------|-----|--------------------|--------|-----|
| | High | Medium | Low | High | Medium | Low |
| Evolving | ✓ | | | ✓ | | |
| Inclusive | | | ✓ | | ✓ | |
| Engaging | | ✓ | | | ✓ | |
| Balanced | ✓ | | | | ✓ | |
| Comfortable | | ✓ | | | | ✓ |
| Robust | | ✓ | | ✓ | | |

CONCLUSIONS

Urban design practices aim at offering the best solutions to enhance public life. Thus, it is a valuable perspective to consider street medians as one of the leftover spaces that should be considered as cities' public recreational spaces. The presented research work investigated the different activities which take place in street medians during different times and on different days. It addressed the concept of spontaneous adaptations within the practiced activities in such spaces through a case study analysis of two selected major street medians. Successful public green spaces need to be evolving, inclusive, balanced, comfortable, and robust, the study shows that street medians encompass high potential to compensate for the low provision of green spaces when they promote these qualities. Results showed that both streets are highly evolving and have high to medium levels of engagement, robustness, and balance. The level of inclusion needs to be enhanced in Gameat Al Dowal Al Arabeya street median to include diverse user groups. In Nahdet Misr street median more shading and seats can enhance the level of comfort. The study recommends that urban design policies can consider street medians as vital green open spaces that should be designed to become user- friendly and suitable for different types of users. Guidelines are required for such spaces to

adopt various interventions from users. The presented study findings and conclusions point out suggestions for future investigations like; empirical investigation of the impact of landscape design elements on activities and interventions generated by users of different street medians. Also, investigating the diversity of socio-cultural aspects on the perception and use of the community for these spaces.

ACKNOWLEDGMENT

The authors would like to thank arch. Nour Sameh, arch. Youssef Ahmed Ewais and arch. Ahmed Mohamed Abd El-Salam for their help in the data collection.

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