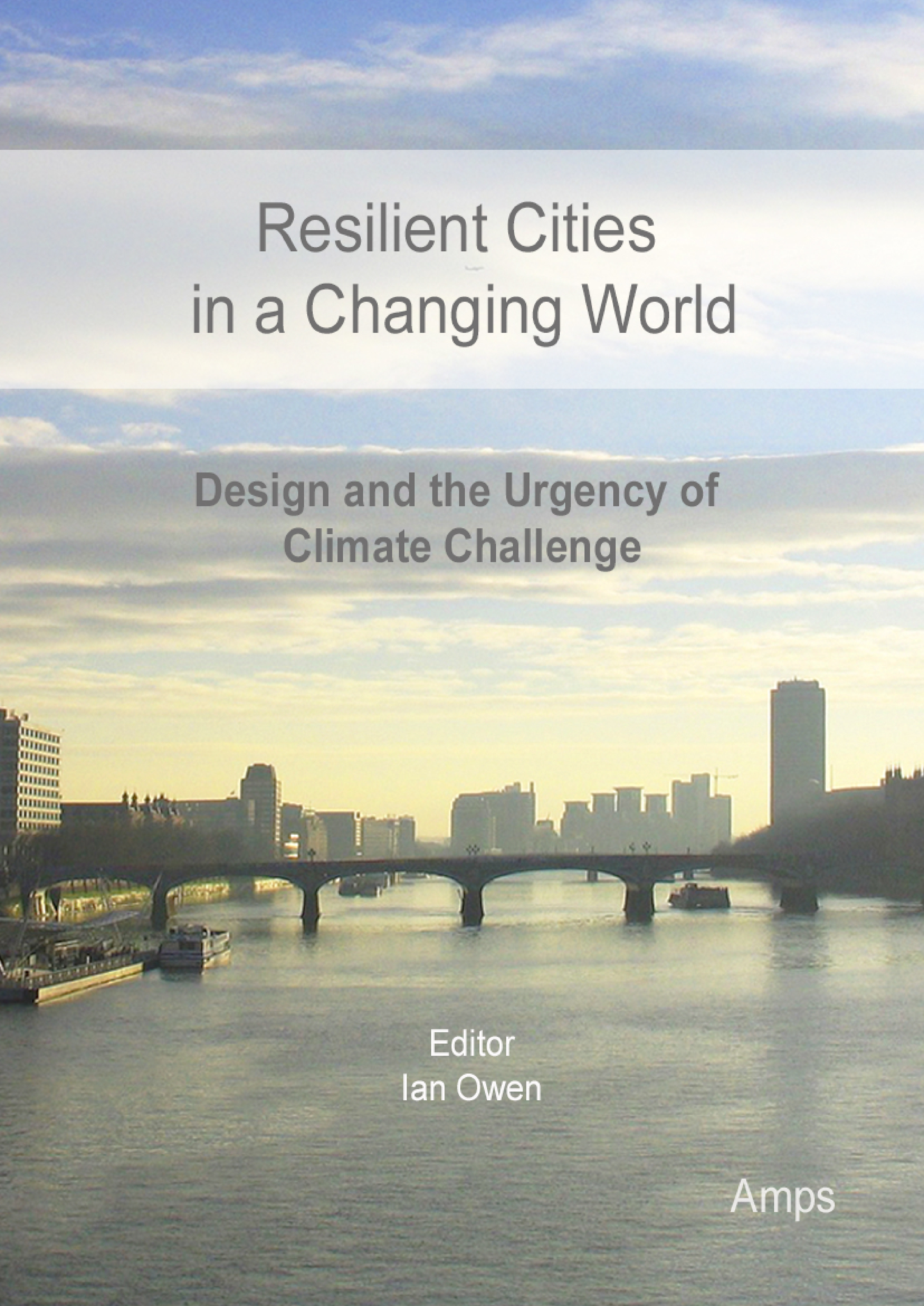

Resilient Cities in a Changing World

Design and the Urgency of Climate Challenge

Editor
Ian Owen

Amps

Resilient Cities in a Changing World: Design and the Urgency of Climate Challenge

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INTRODUCTION

Designing Resilient Cities for a Changing World:

The Urgency of Global Challenges

Cities are at the forefront of some of the most pressing global challenges—such as climate change, urbanisation, sustainability and public health. With nearly 70% of the world's population expected to live in urban areas by 2050, according to the United Nations (UN), cities will play a crucial role in shaping both human well-being and environmental resilience. Central to these challenges is the built environment, which is responsible for nearly 37% of global CO_2 emissions. Cities as a whole contribute around 70%, with buildings alone accounting for approximately 40% of urban emissions. As cities expand, the dominance of concrete, steel and glass exacerbates the urban heat island effect, increases energy consumption and places significant strain on water, air and food systems. Yet, the built environment is not just a contributor to these problems—it is also a powerful driver of sustainable solutions. Urban centres hold the greatest potential for transformation, serving as testing grounds for policy innovation, green technology and community-driven adaptation strategies.

Climate change is no longer a distant threat but an immediate reality. Rising global temperatures are triggering extreme weather events, from devastating wildfires in California and Australia to catastrophic flooding in July 2021—when severe floods in Germany and parts of Western Europe (including Belgium, the Netherlands, and Luxembourg) caused widespread destruction and loss of life, and record-breaking rainfall in China's Henan province, particularly in Zhengzhou, led to severe damage and a loss of human life. Coastal cities are confronting rising sea levels, while landlocked urban city centres face intensifying heat waves and shifting climate patterns. These disruptions threaten critical infrastructure, displace populations and exacerbate social inequalities, particularly in low-income and marginalised communities that are often located in areas most vulnerable to climate risks. In many cities, these communities also have fewer resources to adapt, whether through access to cooling infrastructure, resilient housing or financial support to rebuild after disasters.

That said, sustainability is not just about reducing emissions—it's about creating resilient systems that support both human and ecological health. The COVID-19 pandemic in 2019 underscored the interdependence of urban health, environmental conditions and social policies. Public spaces became critical lifelines, reinforcing the need for accessible green areas, pedestrian-friendly streets and improved air quality. During lockdowns, outdoor activities in Oslo surged by 291%, underscoring the vital role of green spaces in urban settings. Likewise, studies have shown that 43.2% of the public reported using green spaces for relaxation more often than before the pandemic. At the same time, the crisis exposed vulnerabilities—from supply chain disruptions to housing insecurities—forcing cities to rethink their infrastructure, governance and preparedness. While some local governments implemented temporary policies to create safer streets and expand pedestrian zones, the long-term question remains: will cities commit to making these adaptations permanent?

While much attention is given to the role of cities in tackling climate change, urban resilience cannot be considered in isolation. Rem Koolhaas' Countryside. A Report (2020) challenges the dominant urban-centric perspective, arguing that the future of sustainability depends on rethinking the relationship between cities and the countryside. Often dismissed as peripheral, the countryside plays a fundamental role in global sustainability—acting as a source of food production, resource extraction, biodiversity conservation and carbon sequestration. As urban populations grow, cities remain dependent on rural areas for everything from energy supply to waste management, yet policies often fail to account for this interdependence. Koolhaas highlights how radical sustainability experiments—such as AI-driven agriculture, rewilding and off-grid energy solutions—are already taking shape outside of dense urban environments. This book, while focusing on the urban landscape, acknowledges that resilient and sustainable cities must engage with these broader ecological systems rather than operate in isolation.

These disruptions have accelerated the conversation around urban sustainability, resilience and equitable development, reinforcing the need for cities to adopt integrated approaches that combine architecture, technology, policy and community engagement. Previous urban planning models often worked in silos, with sustainability initiatives failing to integrate social equity, or climate action plans being developed separately from public health policies. To avoid these fragmented responses, cities must take a more holistic approach—one that embeds resilience across multiple sectors and prioritises long-term systemic change over short-term fixes. This book responds to this critical moment by bringing together research from multiple disciplines to explore how urban environments can evolve in the face of global challenges. Through case studies from New York, Nottingham, Chengdu, Catania and Harbin, it not only seeks to understand these challenges but also provides a practical roadmap for cities to become sustainable, adaptable, inclusive and prepared for the complexities of the 21st century.

A Roadmap for Sustainable and Resilient Cities

The book is structured into five key sections, each addressing key aspects of urban climate resilience, sustainability and adaptation. Section 1: *Urban Sustainability, Climate Resilience & Adaptation Strategies* explores broad sustainability themes, focusing on resilience planning, climate adaptation and urban vulnerability. It includes studies on climate-responsive urban planning, environmental justice and strategies for integrating socio-demographic data into heat vulnerability assessments. Case studies, such as those on climate gentrification in Miami and the influence of street tree growth on pedestrian thermal comfort in Harbin, provide valuable insights into the overlapping challenges of urban development, climate risk and social equity.

Section 2: *Decarbonisation, Energy Transitions & Climate Adaptation* delves into the policies, strategies and technological advancements that drive urban decarbonisation efforts. It examines energy transitions, emissions reduction frameworks and the role of performative strategies in sustainable urban development. Studies in this section assess the socioeconomic factors influencing CO_2 emissions, explore the impacts of Local Law 97 in New York and evaluate urban energy modelling tools such as the EU City Calculator. Additionally, it highlights how artificial intelligence is shaping climate adaptation policies, while educational initiatives like the Urban Tech Curriculum equip future professionals with the knowledge to implement climate-positive strategies.

Section 3: *Circular Economy, Adaptive Reuse & Resource Efficiency in Urban Environments* focuses on sustainable resource management in cities. It examines strategies for waste reduction, material efficiency and the adaptive reuse of buildings to reduce embedded carbon. The research presented includes studies on community-informed reuse practices, circular urbanism and human health implications of building materials. These perspectives contribute to a deeper understanding of how cities can transition toward more regenerative design approaches, reducing waste while maintaining economic and social viability.

Section 4: *Urban Morphology, Spatial Planning & Social Innovation* investigates the spatial organisation of cities, urban morphology and the social dimensions of planning. It includes studies on typologies of production-based cities, subsurface spatial planning and the role of participatory urban design processes in fostering livable cities. Additionally, this section explores social innovation in architecture, looking at how evolutionary design principles can enhance urban development and community resilience. Case studies, such as the transformation of Catania's historic fish market, illustrate the complexities of balancing economic development, cultural preservation and environmental sustainability in urban settings.

Section 5: *Nature-Based Solutions, Biodiversity & Urban Green Infrastructure* examines the role of green infrastructure, biodiversity and biophilic urban design in enhancing climate resilience. Research in this section explores the multi-disciplinary benefits of biodiverse urban spaces, blue-green infrastructure planning and the integration of nature into the built environment. It includes studies on small-scale biophilic interventions, the psychological benefits of nature exposure in cities and the role of environmental education in fostering sustainable mindsets. By highlighting the relationship of ecology, public health and urban design, this section underscores the importance of embedding nature-based solutions into future city planning.

Moving Forward: Building Resilient Cities Together

The challenges cities face today are complex, layered and urgent. However, they also present unprecedented opportunities for innovation, collaboration and transformation. This book serves as both a critical examination and a practical guide, offering insights from diverse global contexts to inform the way forward. Whether you are an urban planner, architect, policymaker, researcher or engaged resident, the ideas and case studies presented here aim to inspire new ways of thinking about the built environment. Designing resilient cities is not just about mitigating risks—it is about reimagining urban life to create more inclusive, thriving and regenerative spaces for future generations.

Ian Owen.

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SECTION ONE

CLIMATE GENTRIFICATION PATHWAYS AND RESILIENCE: POLICY AND PLANNING DISCOURSES IN MIAMI

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INTRODUCTION

Cities are responding to climate impacts, and people are feeling pressured to move. Climate gentrification scholarship can illuminate shifting investment patterns associated with displacement pressures that threaten resilience. This critical discourse analysis asks, how might resilience policy and planning play a role in climate gentrification pathways? Using the case of Little Haiti, Miami, I suggest expanding a climate gentrification framework to assist policy makers in understanding the interplay of economic and social factors, as well as policy impacts, facilitating more nuanced solutions.

A combination of socioeconomic factors plus climate change impacts and responses may translate to direct and indirect displacement pressures. Climate gentrification (CG) theory predicts shifting urban or regional development patterns toward areas of lower risk or lower cost and accompanying shifts in property values.[1] People in gentrifying areas may experience reduced access to familiar goods and services or shifting cultural identity, among other social and health impacts.[2] Access to jobs, schools, and social capital may be impacted.[3] Low-income, underrepresented, and immigrant persons tend to bear disproportionate climate and climate policy impacts including displacement.[4] Little Haiti, Miami serves as an illustrative case for study because the community faces direct and indirect displacement pressures, repeating patterns of segregation and marginalization,[5] as a massive scale development project threatens housing affordability and cultural identity. In this project, I aim to spotlight potential drivers and impacts of community displacement, including loss of social capital, heritage, and economic and spatial stability, especially in ethnic enclaves.

First, I propose an expanded view of the CG pathways. Then, I highlight the methodology of critical discourse analysis applied to the case of Little Haiti to explore CG pathways. In this study, I examine institutional and community discourse. Finally, I share the findings and implications for scholarship and policy.

EXPANDING CG PATHWAYS

In its original definition, gentrification refers to the transition of a neighborhood due to an influx of investment.[6] Neighborhood changes, including the loss of social connections, transformed public facilities, transportation patterns, and support services, can produce the pressure of displacement in advance of an actual move.[7] Resource displacement can stimulate other kinds of displacement, such as loss of sense of place.[8] The concept of gentrification expanded to include "other/new forms of social upgrading, other/new actors and other/new spaces."[9] Gentrification includes potential residential, cultural, or job displacement due to individual, market, or government intervention, often in the form of investment.[10]

Keenan, Gumber, and Hill proposed a three pathways theory of CG, showing how climate change impacts may drive investment and settlement patterns.[11] Pathway One is investment choices, for example, development in areas of lower risk. Pathway Two is increased consumer cost burdens, for example, due to repairs, higher insurance premiums, or climate adaptation costs. Pathway Three is public resilience investments, for example, storm surge infrastructure, greening, or even broader resilience efforts that drive up the property value. I propose an expansion of the pathways to acknowledge additional factors.

CG Pathway One: Superior Investment

Developers' investment patterns may contribute to CG. After Hurricane Katrina, which damaged 70 percent of New Orleans' occupied housing stock, the influx of post-disaster investment was associated with further or permanent displacement.[12] Only 57 percent of the city's Black population returned, and as rebuilding efforts drove up housing prices, the ability of residents to return to the city split along racial and economic lines.[13] In Miami, areas protected from flooding may be targeted for investment and experience more rapid real property price appreciation than other areas, while lower, flooding-prone elevations may be less attractive and fail to keep pace in price appreciation.[14] Scholars debate whether Miami gentrification stems from rational climate impact investment behaviors and other market forces, such as a steady march of development outward from downtown, escalating property values, and insufficient housing and resident protections.[15] This project underlines the idea that private investment may also be influenced by public policy.

CG Pathway Two: Cost Burden

Climate change impacts of extreme heat and flooding add disparate housing-related cost burdens, also recognized as a pathway to climate gentrification.[16] Cost burdens are distributed unevenly. For example, higher-income households tend to pay less for utilities while consuming more energy per capita and square foot due to greater energy efficiency.[17] Low-income households are more likely to be under- or uninsured as homeowners or renters.[18] Homes of lower-income households are more likely to have moisture and mold due to flooding, storm-related and higher-energy demand power outages, and damage due to drought-related wildfires and storms.[19] Such expenses impact communities financially. However, this paper explores additional sociocultural cost burdens.

CG Pathway Three: Resilience Investment and Intervention

Resilience scholarship examines population displacement arising from conflict and war, development and infrastructure construction, disasters, and crises, including environmental factors such as climate change.[20] Keenan and colleagues' third CG pathway embraces climate resilience or sustainability investment associated with rising property values and displacement pressures. Yet resilience policy may undermine community resilience.[21] A growing body of academic literature and activism identifies communities put at risk by resilience measures that retrench historically exclusionary, extractive, racist or classist policies.[22] Community resilience is compromised, not only by disasters and demographic and social factors, but also by the concentration of power, land, and resources; voter disenfranchisement and disruptive politics; forced relocation and exposure to hazards.[23] This paper suggests expanding this pathway to include policy and planning interventions.

ANALYZING DISCOURSES

This project critically analyzed discourses related to CG in Miami, Florida. Institutional discourse consisted of resilience strategies and urban planning policy as well as transcripts of public meetings during a period of heightened climate planning and action (2016-2021). A search for the term "gentrification" in Miami City public records produced 273 results (see supplemental material). Community discourse comprised of letters to the city commission, submissions of public comment, and statements of objection related to the public meeting transcripts. In addition, I organized a community writing workshop and focus group in Little Haiti, Miami. The workshop transcript recorded the poetry shared by participants and the ensuing focus group discussion. I scrutinized these documents using critical discourse analysis.

Critical discourse analysis (CDA) serves as an explanatory and normative critique.[24] CDA emphasizes *history, power, and ideology* to consider discourse broadly defined in institutional, political, gender and media spaces, sometimes advocating for marginalized groups.[25] CDA's primary goal is to study complex social phenomena that may benefit from a multi-disciplinary and multi-methodical approach.[26] CDA lends itself to the hermeneutic approach, a way of "grasping and producing meaning relations," which I used to link the text to its wider context and consider author intentionality.[27] With its emphasis on power and institutions, revealing dominant and alternative discourse, CDA aligns with the goal of diversifying participation in democratic policymaking and planning. For the case of Little Haiti, Miami, CDA provided a useful method of analysis.

The Context of History and Power

Immigrants to Miami faced a segregated city. At the time of Miami's founding, real estate and railroad mogul Henry Flagler and other influential Miamians drew the city's boundaries to segregate along racial and economic lines and defined undesirable land usage outside these borders.[28] "North Miami," the area between downtown and Lemon City, became the area where the Florida East Coast Railway workers lived, most of whom were African American.[29] This was also the area where saloons and prostitution were allowed to operate until such vice businesses were pushed into a red light district within Colored Town.[30] Areas north of Miami's business district were considered less desirable for real estate development, but more suited to transportation and commercial activities such as shipping and light manufacturing, because they lay three feet higher above sea level than areas to the south.[31]

Like other American cities, Miami experienced redlining. Redlining, a practice established during the New Deal era by the Homeowners Loan Corporation that denied financing in non-White neighborhoods, has implications for contemporary segregation and gentrification.[32] Figure 1 shows Miami's historic redlining map. The yellow rectangle indicates current day Little Haiti superimposed within the red or "D-grade" area, far from the yellow circle, Miami's Central Business District. Decades later, Miami reflected this legacy, being rated the nation's most segregated city.[33]

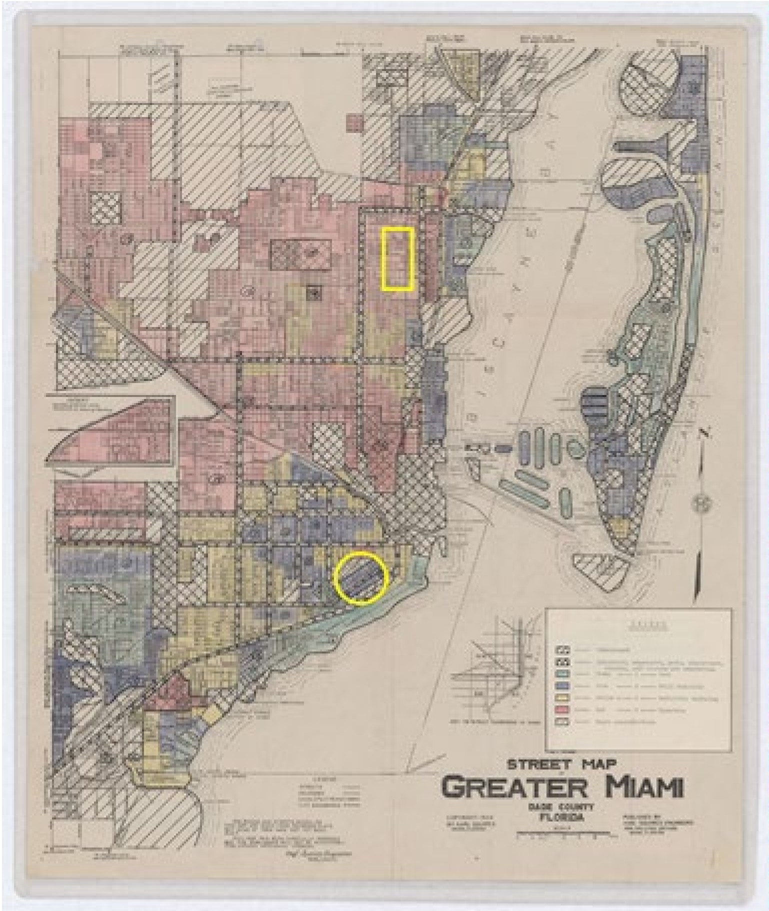

Figure 1. Redlining map of Miami, c. 1935 with contemporary Little Haiti and central business district

Haitian immigrants have been regarded with a higher level of suspicion and mistrust than other immigrant groups, stigmatized as "boat people" associated with the underinvested community of Little Haiti.[34] Nevertheless, Haitians continued to flee the island due to the political and economic emergency accompanying the Duvalier dictatorship,[35] as well as natural disasters such as Hurricane Flora in October 1963, which decimated the country.[36] Since then, Little Haiti experienced poverty at a rate of 46.2 percent, well over the City of Miami at 30 percent.[37] Despite these challenges, art galleries, museums and bookstores contributed to the area described as "the cultural heart of the Haitian diaspora."[38] Little Haiti provided an escape from rising cost burden elsewhere in the city, for example, gentrifying areas to the south and east.[39] The community of Little Haiti fought to maintain its cultural identity, and after years of supporters' lobbying, the City of Miami designated Little Haiti as an official neighborhood.[40]

Since 2016, a wave of climate resilience policy action in Miami, peppered with stated goals about equity, coincided with multiple large-scale development proposals for Little Haiti that threaten the community's stability. Development of the $1 Billion Magic City Innovation District (MCID) could displace more than 3,000 low-income, cost-burdened households.[41] On one hand, the project aligns with regional resilience priorities to develop flood resistant areas; yet accelerating property values threatened geographic and financial stability for a community consisting mostly of renters.[42]

Resilience Ideology

The National Academies of Science, Engineering, and Medicine adopted this definition of resilience: "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events."[43] Resilience policy has been critiqued as a narrative of neo-liberal politics and policies, either as a pro-market extension of governance tools, or a denunciation of social control over underrepresented, often minority populations, depending on one's outlook.[44] Examination of institutional and community discourse revealed these perspectives.

Institutional Discourse

In recent years, the City of Miami has embraced the resilience ideology, *Miami Forever*. Miami's induction into the Rockefeller Foundation's 100 Resilient Cities program provided financial support and guidance to "build resilience to the physical, social, and economic challenges" faced by modern cities,[45] led in 2019 to its first comprehensive strategy for mitigation, adaptation, and communication: *Resilient305*. Greater Miami employed *Resilient305* to harmonize individual comprehensive strategies and action plans to build resilience within jurisdictions and throughout the region.

Miami voters passed the $400 million Miami Forever bond to "build a stronger, more resilient future for Miami."[46] Miami collected input by consulting with experts on topics including housing affordability and climate gentrification and by holding workshops with residents. After the Southeast Florida Regional Climate Compact released the Regional Climate Action Plan 2.0, Miami released its own climate action plan. The City of Miami 21 Zoning Code was comprehensively updated following the formation of a task force in December 2019.[47]

The Miami-Dade Sea Level Rise Strategy[48] advised a planning process related to hazard risk and vulnerability assessment that included public engagement. Miami, thirty-three other municipalities, and the unincorporated areas. Five adaptation approaches are recommended: 1) raising the land, 2) elevating structures, 3) building on high ground near transit, 4) expanding waterfront parks and canals to alleviate flooding, and 5) creating additional spaces for water in neighborhoods.

Simultaneously, Miami endured an affordable housing crisis.[49] A notable planning intervention was the updating of Miami 21 zoning code, including a mechanism, the Special Area Plan (SAP), with significance in the context of Little Haiti. The SAP allows a developer to master plan assembled parcels of nine acres or more to include mixed-use development.[50] That is, SAPs, a form of Planned Unit Development (PUD), designate a new zone for a single landowner/single location exception to traditional zoning schemes in which residential, commercial, and industrial zones are segregated.[51] PUDs provide an antidote to homogenous, sprawling communities[52] and promote denser development and the conservation of natural environments, thus supporting environmental goals under the auspices of "New Urbanism."[53] However, the PUD "By Right" model provides a streamlined path to a building permit as it sidesteps public input,[54] and New Urbanism draws criticism as presenting a façade of social improvement while entrenching the old social order.[55]

CG scholarship enfolds the concept of environmental and resilience gentrification, emphasizing how climate change impacts and responses may influence property markets and delineate urban geographies of social difference.[56] Scholars warn of disparate outcomes for climate resilience strategies in comparing benefits to underserved populations and wealthier, white neighborhoods.[57] Therefore, the role of policy and planning in displacement impacts should be identified, addressed, and reflected in CG Pathway Three: Resilience Investment and Intervention.

Community Discourse

Long before mega-scale development projects were proposed for Little Haiti, community discourse in city commission meetings revolved around affordable housing, financial and social costs and benefits, (renewed) displacement, and climate change impacts. An advocate voiced the concerns of residents of Little Haiti and other ethnic enclaves who want to "keep their residence…to be City of Miami residents…the city has the obligation of helping them to keep those new constructions affordable.[58] A resident expressed outrage over renewed displacement, "We are in a time where developers…are seeking to take an entire neighborhood from the people who have lived there; from the people who sought refuge from an island, and found a home, and made a way in this City.[59] During the debates on the $1 Billion MCID, the community warned, "[T]he project risks deeply altering the housing affordability, its demographics and cultural heritage."[60]

Four years after the approval of the MCID, I convened a community writing workshop and focus group on climate gentrification in Little Haiti on March 27, 2022. The resultant poetry and discussion revolved around themes of recurrent displacement, misalignment of institutional and community values regarding housing, and concern about the loss of place. The rooster is highlighted as a symbol of cultural identity.

"Searching for a place to plant your seed, instead sprouting where the wind blows like a weed. This is all we've known, so we roll" (Workshop participant 1, female).

"Whatever the solutions are…they are doomed to fail…because people do not share our values" (Workshop participant 2, male).

"I notice all the roosters here, and I know that this is a beautiful location, and I hope that it stays here, and it does not get gentrified" (Workshop participant 3, female).

Themes found in community discourse aligned with Pathway One: Private Investment Choices, as they expressed how the MCID threatened to accelerate housing costs and precipitate displacement, and with Pathway Two: Cost Burdens—Financial, Social, Cultural with references to housing affordability, cultural ownership and loss.

IMPLICATIONS FOR CG PATHWAYS

Scholars urge expanding the CG pathway-oriented theory into a more complex process embedding social, geographical, and environmental perspectives.[61] As a result of this study, I propose expanding Keenan et al.'s[62] CG pathways framework in Figure 2. Little Haiti, Miami provides evidence within community discourse for updating Pathway Two to reflect social and cultural cost burdens.

The strategies advocated in the Miami-Dade Sea Level Rise Strategy have the potential to elevate the resilience of the Miami region while also exacerbating gentrification in some neighborhoods as noted in the updated CG Pathways framework. Related to Pathway Three, adaptation investments such as "expanding waterfront parks and canals" and "creating additional spaces for water" can lead to green gentrification or the transfer of vulnerability to other, less well protected areas.[63] "Building on high ground near transit" has the clearest connection to the situation in Little Haiti (due to its location and relative elevation) and the potential to encourage climate gentrification under Pathway One of the framework. In this case Pathway Three impacts Pathway One. Raising the land and elevating structures may increase cost burdens for property owners that may also transfer to renters, or prompt an abandonment of flooding areas, promoting CG under Keenan's Pathway Two. Furthermore, social and cultural costs, particularly for underserved communities, should also be noted.

In summary, Figure 2 suggests an expanded concept of the CG pathways framework with three additions. Pathway Two now reflects socioeconomic (not merely economic) cost burden. Pathway Three includes resilience and planning intervention, an expanded concept that includes the previously depicted resilience investment. Finally, a connection is drawn between the public interventions of

Pathway Three and the private investment of Pathway One. Indeed, the actions and recommendations along any pathway may influence the others, a potential subject for future scholarship.

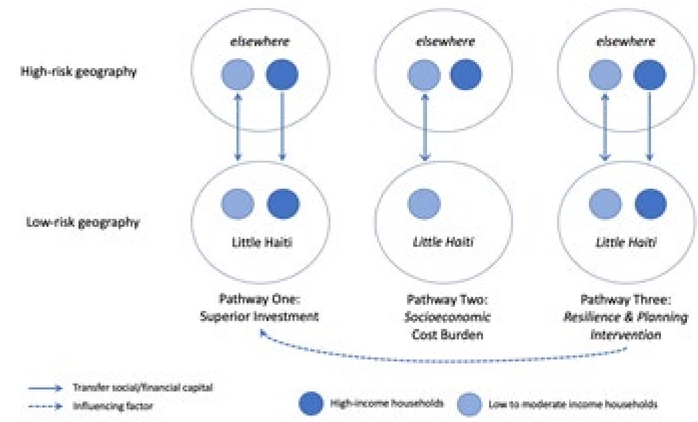

Figure 2. Expanded Pathways to Climate Gentrification, an update of Keenan et al., 2018 Note: Italics and the dotted arrow represent changes from the original

PLANNING AND UNINTENDED CONSEQUENCES

The MCID project illustrates the interplay of market forces, urban planning, and resilience strategies with implications for equity. Real estate mega speculation can undermine communities historically subject to class- and race-based dispossession and displacement—diminishing capacity for resistance and increasing susceptibility to ongoing involuntary mobility.[64] Furthermore, such massive speculation projects heighten tensions and inequalities throughout the urban fabric; investment in previously underinvested areas can undermine resilience.[65] Zoning mechanisms that support density and allow developers to bypass public comment have their uses in the appropriate context. Certainly, NIMBYism (the "not in my backyard" mentality) has thwarted many multifamily housing projects. However, zoning for higher density can result either in displacement or the support of affordable housing,[66] so, like other approaches, must be implemented thoughtfully. Resilience strategies meant to address housing goals and climate impacts may also undermine resilience.

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QUANTIFYING SEISMIC RISK FOR HISTORIC ALGERIAN URBAN CENTERS USING FRAGILITY FUNCTIONS

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INTRODUCTION

Algiers, like many cities in seismically active regions, faces a significant risk from earthquakes. A large portion of the building stock in Algiers, particularly those constructed before the 1960s, consists of low- and mid-rise unreinforced masonry (URM) buildings. These buildings, typically constructed with stone, brick, or light steel framing, often lack the structural capacity to withstand strong earthquakes.
Their inherent properties – high rigidity, low tensile and shear strength, and limited ductility – make them particularly vulnerable to seismic damage. This vulnerability was tragically evident during the earthquakes that struck Ain-Temouchent in 1999 and Boumerdes in 2003, where extensive damage was observed in URM structures.
In recent decades, seismic vulnerability assessment has become a crucial tool for mitigating earthquake risk.[1] Since URM buildings represent a significant portion of the global building stock, earthquake risk reduction strategies must prioritize their evaluation.[2]
Seismic risk assessments identify buildings most susceptible to damage during an earthquake.[3] These studies play a vital role in mitigating future losses by informing:

- *Strengthening interventions*: Vulnerability assessments help target retrofitting efforts towards buildings most in need of improvement.
- *Disaster management plans*: By identifying vulnerable areas, these assessments can guide emergency response and recovery plans.

These goals can be reached by using seismic vulnerability and fragility curves which are essential tools used in risk assessments.[4]

- *Vulnerability curves* estimate the average level of damage expected in buildings with similar characteristics for a given earthquake intensity.
- *Fragility curves* represent the probability of a building reaching a specific damage state (e.g., slight, moderate, severe) for various earthquake intensities.

To build these curves, several methodologies have been developed. Then to assess the vulnerability of URM buildings, the developed methods include:

- *Vulnerability index methods*: These methods classify buildings based on vulnerability scores derived from their structural characteristics.[5]
- *RISK-UE method*: This method incorporates vulnerability, exposure, and economic data for regional risk assessment.[6]

• *Rapid Visual Screening (RVS)*: This methodology provides a quick assessment based on a visual inspection of the building.[7]
• *Damage Probability Matrices (DPM)*: These matrices provide the probability of different damage states for various building typologies and earthquake intensities.[8]
• *HAZUS methodology*: It uses a combination of building inventory data, hazard intensity maps, and damage relationships (called fragility functions) to estimate potential losses from earthquakes, floods, and hurricanes. This allows planners to identify vulnerable areas and prioritize mitigation efforts.[9]

This study aims to develop fragility curves for URM buildings in Algiers using vulnerability curves derived from a vulnerability index method. The district of Belouizdad will serve as a case study to demonstrate the application of these fragility curves in seismic scenario development.

By incorporating recent research on URM building fragility,[10] this study will contribute to a more comprehensive understanding of seismic risk in Algiers and inform strategies for mitigating earthquake damage in the city's URM buildings.

TECHNICS AND METHODS

Vulnerability index method

The Vulnerability Index method (VI) is a quantitative approach for assessing the seismic performance of buildings. It assigns a numerical score (VI) to each evaluated building. This score is obtained by summing the vulnerability levels of various structural and non-structural parameters that influence the building's seismic behaviour. Similar VI methods have been established for reinforced concrete,[11] reinforced masonry,[12] and steel structures.[13]

In this study, twelve (12) key parameters are identified. The vulnerability level of each parameter (denoted as coefficient Ki) is categorized into four classes. Class C1 represents a condition compliant with the current Algerian seismic code. Classes C2 and C3 correspond to configurations that satisfy older Algerian codes, while C4 signifies an unsafe configuration. The specific Ki values, detailed in Table 1, are derived from a statistical analysis of past earthquake data in Algeria.[14]

Equation 1 will subsequently express the Vulnerability Index (VI).

$$VI = \sum_{1}^{12} ki \quad (1)$$

Parameter	Coefficient ki			
	C1	C2	C3	C4
Shear resistance	0	0.05	0.12	0.21
Plan regularity	0	0.01	0.04	0.07
Elevation regularity	0	0.01	0.04	0.07
Wall connection	0	0.03	0.07	0.10
Wall type	0	0.01	0.03	0.05
Floor	0	0.01	0.03	0.05
Roof	0	0.01	0.03	0.05
Soil condition	0	0.02	0.06	0.10
Pounding effect	0	0.01	0.04	0.07
Modifications	0	0	0.04	0.07
Details	0	0.03	0.02	0.03
Geneal maintenance	0	0,03	0.08	0.13

Table 1. Values of weighting parameters

This study proposes a three-tier vulnerability classification system (Green, Orange, Red) for masonry structures, detailed in Table 2 and Figure 1.[15]

Class	P1-green	P2-orange	P3-Red
VI	0.0-0.20	0.20-0.06	0.06 -1.00

Table 2. Classification of URM structures by vulnerability index

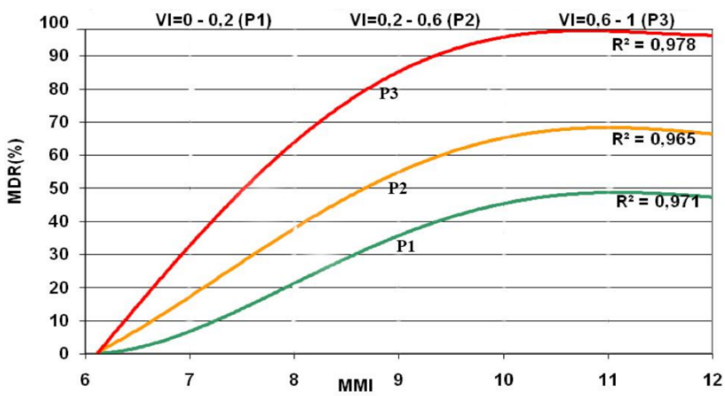

Figure 1. Vulnerability curves based on URM structures classification

URM buildings in Belouizdad-Algiers

This study investigated unreinforced masonry (URM) buildings in Belouizdad, a district east of Algiers. The district covers an area of 2.16 km² with a population density of 20,394 inhabitants/km². Notably, Belouizdad boasts 643 URM buildings, primarily constructed with stone or brick walls averaging 60 cm in thickness and featuring vaulted floors.

Historical context

It's important to recognize the historical significance of these Algerian masonry structures. Built during the colonial era (1830-1962), they represent a period of substantial urban and architectural development in Algiers. This development unfolded in four distinct phases: 1830-1854, 1854-1881, 1881-1915, and 1915-1962.

Buildings surveys

Following the historical background provided earlier, a comprehensive survey was conducted on all 643 URM buildings in the Belouizdad municipality. This survey utilized a developed data sheet.
The collected data was then meticulously recorded within a Geographic Information System (GIS). This approach facilitates data management, visualization, and interpretation, ultimately leading to more insightful results. A visual representation of the commune within the GIS is provided in Figure 2.

Figure 2. URM buildings in the district of Belouizdad

Buildings distribution and historical phases

The survey revealed a distribution of building heights ranging from single-story (level 1) to seven stories (level 7). Figure 3 detail this distribution. As evident, two-story buildings dominate, comprising 34.21% of the total. Buildings with a ground floor and second floor follow closely, each representing approximately 20%. Notably, these three categories collectively account for over 70% of the URM structures. Buildings with a higher number of stories are proportionally less frequent.

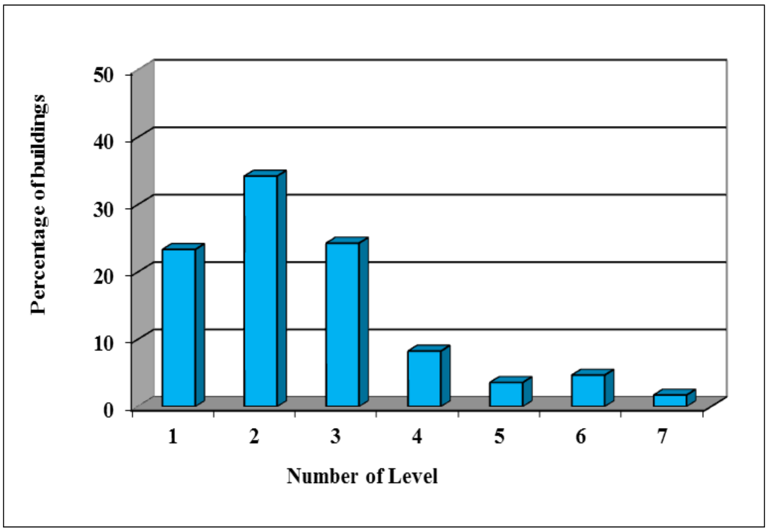

Figure 3. Distribution of buildings by number of level

Analyzing this result through the lens of the historical phases outlined earlier (1830-1854, 1854-1881, 1881-1915, 1915-1962) provides valuable insights (Figure 4):

• *1830-1854:* A very small percentage of buildings exist from this period, reflecting the transition from the Ottoman era to the beginning of French colonization.

• *1854-1881*: This phase witnessed a resurgence in construction activity, marking the early development of the territory under French rule.

• *1881-1915*: This period saw the peak in construction. Notably, an expansion in building heights up to seven stories is observed during this phase. This coincides with the implementation of French legislation in 1884, permitting builders to gain additional floors by utilizing flatter roof designs.

• *1915-1962*: The final phase witnessed a decline in construction compared to the previous period. This decline aligns with the introduction of reinforced concrete construction techniques around 1930.

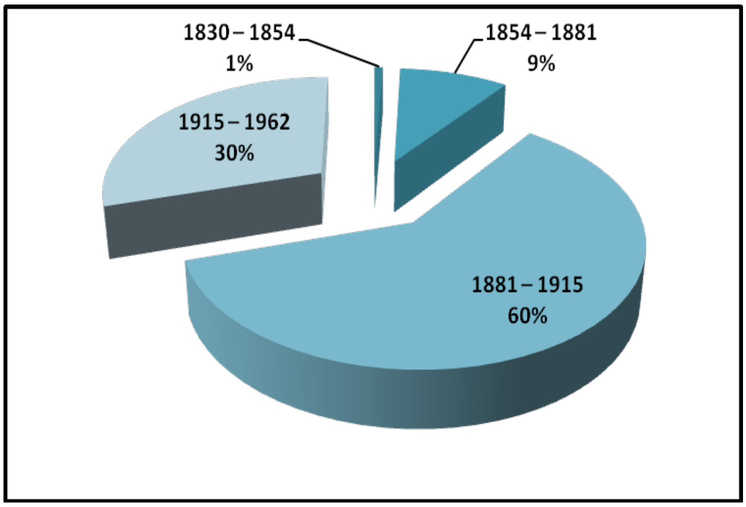

Figure 4. Building distribution by number of floors

By analyzing the building distribution alongside the historical context, we gain a deeper understanding of the construction trends and architectural evolution within Belouizdad. This knowledge proves crucial for assessing seismic vulnerability, as construction practices and materials significantly influence a building's ability to withstand earthquakes.

Seismic vulnerability assessment

Leveraging the building survey data, vulnerability indices were calculated for all URM masonry structures using the established vulnerability index method. The resulting vulnerability scores are spatially represented within the GIS platform (Figure 5).

The analysis revealed that approximately 80% of Belouizdad's masonry buildings exhibit an average level of seismic performance. This is reflected in Figure 5, where vulnerability indices for 508 buildings fall within the 0.20 to 0.60 range, indicating an average vulnerability level. However, it's concerning that nearly 10% of the buildings demonstrate high vulnerability to seismic activity. Identifying these vulnerable structures is crucial for prioritizing mitigation efforts and ensuring public safety.

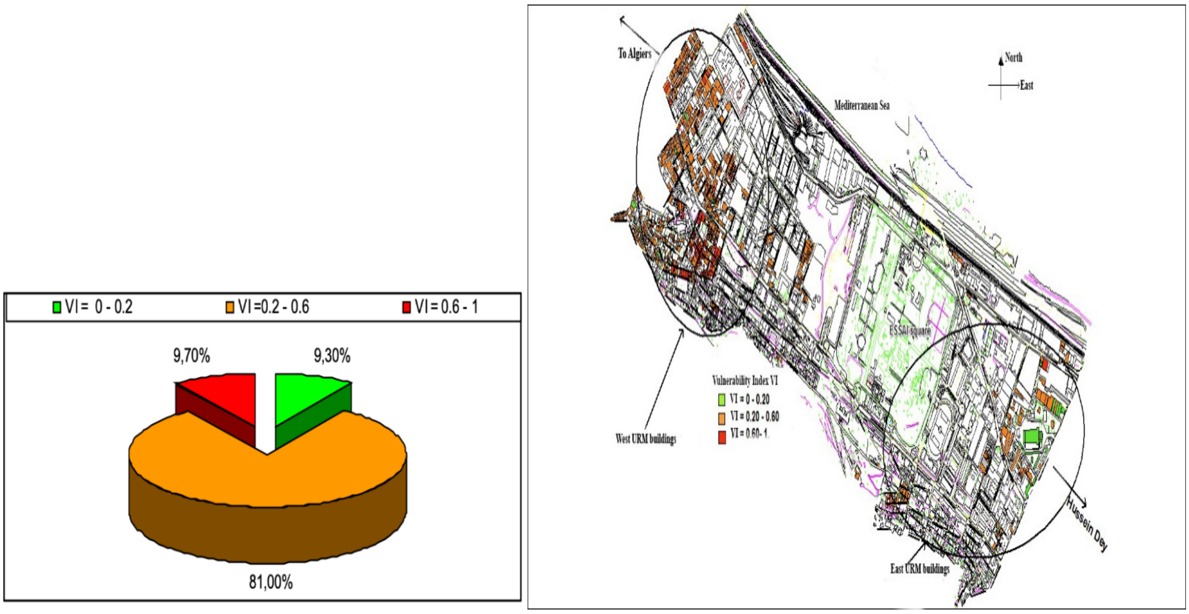

Figure 5. Seismic vulnerability distribution of URM Masonry Buildings in Belouizdad District

Urgent Need for Mitigation

These findings highlight the urgent need for intervention in Belouizdad. Approximately 90% of the masonry buildings exhibit vulnerability to earthquakes. This susceptibility can be attributed to several factors, including:

• *Age of Construction*: Many buildings were constructed during the early phases of French colonization (pre-1915) and may not have incorporated best practices for earthquake resistance.

• *Poor Maintenance*: Over time, a lack of proper maintenance can weaken a building's structural integrity and increase its vulnerability to seismic events.

• *Modifications*: Unauthorized modifications or alterations to the original structure can compromise its stability and seismic performance.

Addressing these vulnerabilities is crucial to safeguard public safety in Belouizdad. The next steps will involve prioritizing buildings for interventions such as strengthening or, in extreme cases, potential replacement.

FRAGILITY CURVES ASSESSMENT

Fragility curves are a critical tool for estimating the likelihood of URM buildings reaching or surpassing specific damage states during an earthquake. These curves typically utilize lognormal functions to model this probability as a function of seismic event intensity. A key strength of fragility curves is their ability to account for the inherent variability in building response. Even buildings classified as the same type may experience different damage levels under the same seismic intensity.

Damage level

To establish a clear link between the Mean Damage Ratio (MDR) obtained from the developed vulnerability curves and the corresponding damage level, the definitions provided by Park and Ang will be utilized.[16]

These classifications will serve as the foundation for constructing fragility functions.

Damage measure and performance level

A crucial step in fragility analysis involves establishing a metric for quantifying the seismic damage sustained by buildings. For URM structures, various frameworks exist for defining damage states. FEMA 356 outlines three performance levels, while HAZUS employs four limit states (Slight, Moderate, Extensive, and Collapse).

This study adopts the limit states defined by Park and Ang to ensure consistency with the damage level classifications used earlier. These limit states will serve as the foundation for developing the fragility curves.

As suggested by Park and Ang, a log-normal distribution offers a suitable representation for the statistical description of building response. The parameters of this log-normal distribution, namely the log-normal mean ($\mu_{\ln D}$) and standard deviation ($\sigma_{\ln D}$).

RESULTS AND DISCUSSION

Constructing fragility curves

Utilizing the log-normal parameters ($\mu\ln D$ and $\sigma\ln D$) derived from the damage ratio distribution we can calculate the probability of exceeding various damage limit states for the URM structures. Equation 2 expresses this probability, where $\Phi(.)$ represents the standard normal cumulative distribution function (CDF). The limit states considered in this study are:

None Damage = 0.01

Light Damage = 0.1

Moderate Damage = 0.2

Severe Damage = 0.5

Collapse = 0.85

By employing Equation 2 and the calculated parameters, fragility curves will be developed. These curves will depict the probability of a URM building reaching or surpassing a specific damage state for different earthquake intensities. This information is vital for seismic risk assessment and informs mitigation strategies.

$$P(D>D_{limstat/I}) = 1- \Phi(\ln(D_{limstat} - \mu_{\ln D})/\sigma_{\ln D}) \quad (2)$$

Visualizing seismic risk: fragility curves

Fragility curves for URM structures are created by plotting the probability of exceeding each damage limit state (None, Light, Moderate, Severe and Collapse) against the corresponding Modified Mercalli Intensity (MMI) values. Figures 6, 7, and 8 display these fragility curves for green, orange, and red URM structures, respectively.

This approach provides a clear visualization of seismic risk. The curves illustrate how the likelihood of URM buildings experiencing different levels of damage increases with intensifying earthquake ground motions (represented by MMI). This information is instrumental for seismic risk assessment and informing mitigation strategies to safeguard these structures.

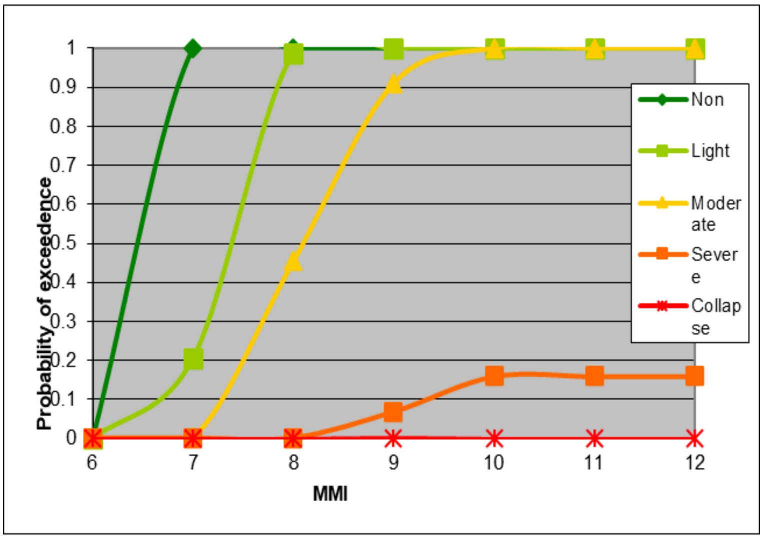

Figure 6. Fitted fragility curves for green URM buildings in Algiers

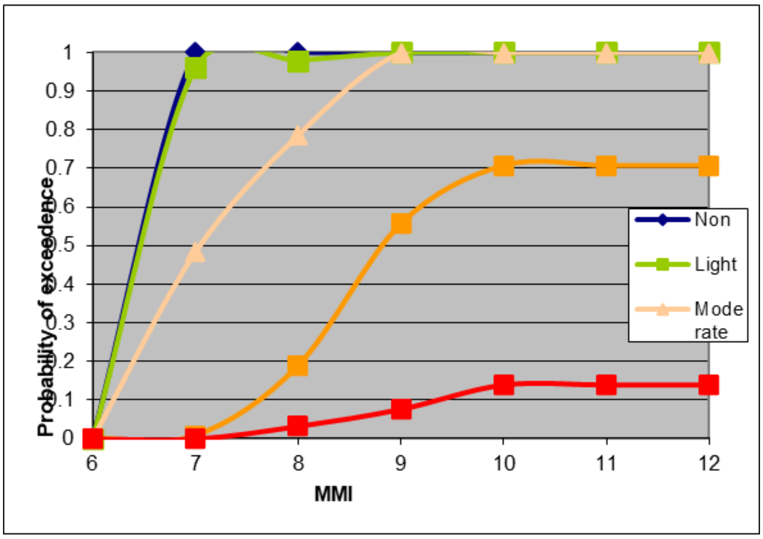

Figure 7. Fitted fragility curves for orange URM buildings in Algiers

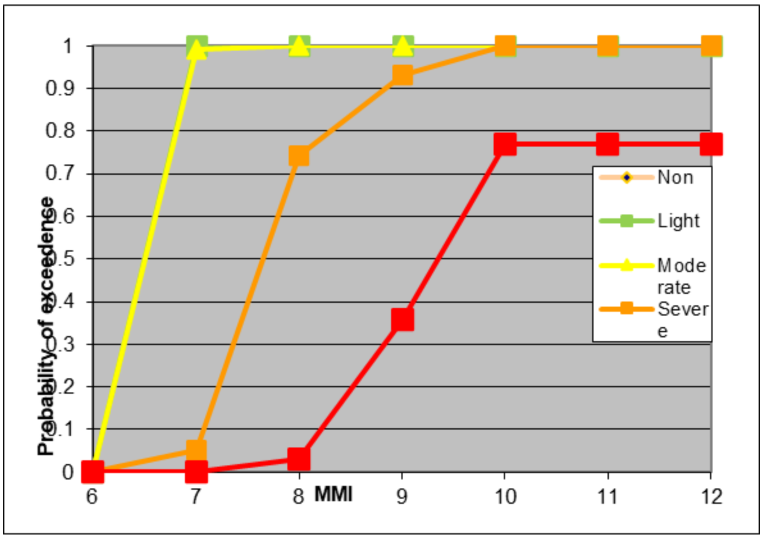

Figure 8. Fitted fragility curves for red URM buildings in Algiers

For buildings belong to red Class (Figure 8) shows, for instance, for an earthquake of intensity 10, the probability of exceeding a damage state “collapse” is 78%, it is 13 % for buildings belong to orange Class (Figure 7) and it is 0 % for buildings belong to green Class (Figure 6). These results are logical in view of the buildings' vulnerability index.

Earthquake Scenario Development

To evaluate the potential consequences of earthquakes in Belouizdad, seismic scenarios were developed for two ground motion intensities: low (MMI 7) and high (MMI 10). These scenarios leverage the fragility curves established for URM buildings in Algiers. A GIS tool was employed to implement these functions and generate the resulting damage distributions.

The anticipated damage distribution for Belouizdad's 643 URM buildings under each scenario is presented in Figures 9 and 10. These figures provide valuable insights into the potential scale of damage for different earthquake intensities. This information is crucial for emergency preparedness planning, risk mitigation strategies, and resource allocation in the event of an earthquake.

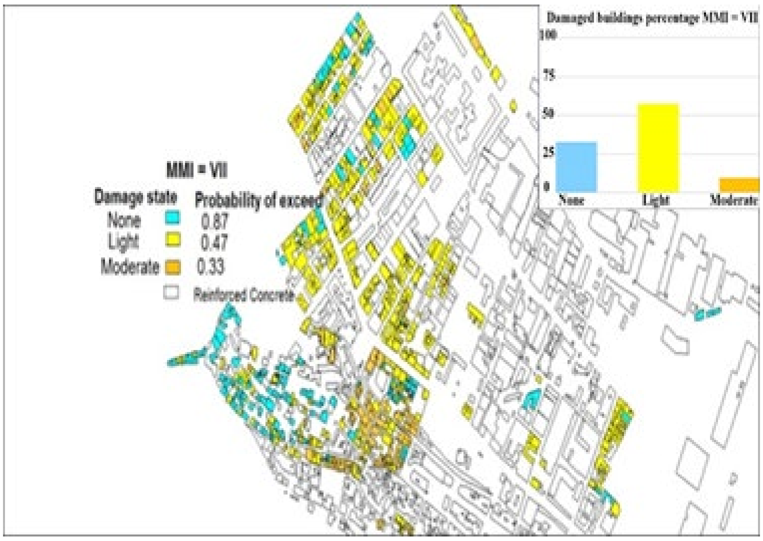

Figure 9. Damage distribution for a Seismic scenario of intensity 7

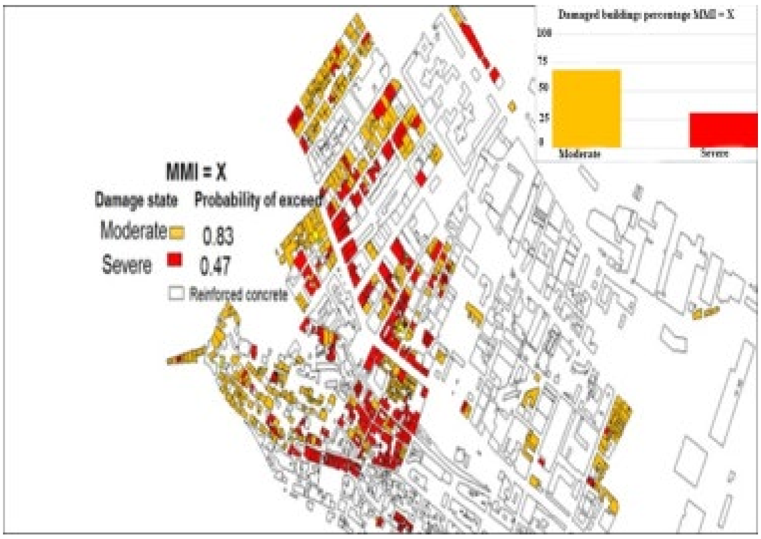

Figure 10. Damage distribution for a Seismic scenario of intensity 10

Seismic vulnerability of URM buildings in Belouizdad

The fragility curves developed for Algiers URM buildings demonstrate a clear correlation between seismic intensity and the probability of exceeding a particular damage state. As expected, this probability increases with intensifying ground motions. Seismic codes typically suggest that inelastic behavior (structural damage) begins for URM buildings around MMI 7, with more severe damage observed at MMI 10.

Our analysis reveals that for a low-intensity earthquake (MMI 7):

- Over 30% of the buildings have a greater than 30% chance of exceeding moderate damage.
- Approximately 18% face a probability exceeding 18% of surpassing severe damage.
- Even a 10% probability of collapse exists at this intensity level.

These findings highlight the inherent vulnerability of Algiers' URM structures, primarily due to their design predating modern seismic codes. Most of these buildings were not constructed with earthquake resistance in mind.

Seismic Scenario Damage Distribution

To assess potential earthquake impacts in Belouizdad, two seismic scenarios were modeled: MMI 7 (low intensity) and MMI 10 (high intensity). These scenarios leveraged the established fragility curves and were implemented within a GIS tool:

MMI 7 Scenario (see Figure 9):

- The majority (58%) of buildings are expected to experience light damage with a probability exceeding 47%.
- Approximately 9% are likely to sustain moderate damage.
- Conversely, 33% have a high probability (over 87%) of experiencing no damage.

MMI 10 Scenario (see Figure 10):

- A significant portion (69%) of buildings, face a probability exceeding 83% of surpassing moderate damage.
- Roughly 31% are likely to experience severe damage with a probability exceeding 47%.
- Only a small percentage (2%) are expected to suffer collapse.

These results align with the overall vulnerability assessment of URM buildings in Belouizdad.

CONCLUSION

This study employed the vulnerability index method to develop fragility curves for unreinforced masonry buildings in Algiers. While vulnerability curves provide an average damage estimate for a region, fragility curves offer a more granular assessment by estimating the probability of exceeding specific damage states for individual buildings under varying earthquake intensities.

The developed fragility curves underscore the seismic vulnerability of Algiers' URM buildings. Several factors contribute to this vulnerability, including:

- Lack of regular maintenance
- Increased building usage due to population growth
- Non-compliance with seismic codes during construction (due to the era of construction)

The importance of fragility curves for accurate seismic risk analysis cannot be overstated. This information is crucial for developing effective mitigation plans, prioritizing interventions for building strengthening, and ensuring public safety in earthquake-prone regions.

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FRAGILITY AND ANTIFRAGILITY IN URBAN SYSTEMS

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INTRODUCTION

Herbert Simon wrote, 'Everyone designs who devises courses of action aimed at changing existing conditions into preferred ones.'[1] It is a generous statement that recognizes design as a basic human activity. It is also a complex statement in that its terms require careful consideration. 'Courses of action' involve the myriad ways and means that might be used to effect change. With these, a designer must accept and manage instrumental constraints—technical, legal, fiscal, etc.—on actions to bring about the new conditions. These limits can be frustrating, but they can also be inspirations for innovation.[2] Perhaps more daunting, though, is establishing what is meant by 'preferred' conditions as the ends of change. Reaching a consensus on what is *good* or even what is *good enough* becomes increasingly difficult as more stakeholders are involved and as the existing conditions are understood in terms of 'wicked problems.'[3]

This essay considers the notion of antifragility as end for urban planning and design. In brief, antifragile systems can improve when exposed to uncertainty and some levels of disruption. They are opposite fragile systems that can only be harmed by disruption and are distinct from robust systems that neither improve nor fail by disruption.[4] As will be discussed below, antifragility has been explored in a variety of disciplines, including urban planning. The contribution of this paper is to consider the idea of antifragility as an aesthetic, where aesthetic is understood not as a narrow interest in outward beauty, but as a broad interest in what is socially perceived and the ways configurations of time and space reflect and express political organization.

The text proceeds in three parts. First, a position on aesthetics within a design framework is articulated. Second, the principles of antifragility are discussed and contrasted with sustainability and resilience, both of which remain important to environmental planning and design practices. Third, an approach from the discipline of art history for comparing compositional strategies is used as a basis to consider the formal qualities of design that contribute to antifragile urban systems. An example is presented.

AESTHETICS WITHIN A CONSTRUCTIVIST DESGIN FRAMEWORK

Design practice—going from an existing condition to a preferred condition—involves resolving ill-structured or ill-defined problems because not all the needed information is available at the start of the process, the criterial for the resolution are rarely known with specificity, and the steps to reach a satisfactory outcome are not obvious.[5] Ill-structured problems become structured or otherwise more tractable by the use of design frameworks which provide assumed a priori relationships between or among elements or steps in a design process.[6] Many frameworks have been devised for environmental planning and design including those by Christopher Alexander, Lawrence Halprin, John Tillman Lyle, Peter Rowe, and Carl Steinitz.[7]

The framework used in this paper differs from the ones mentioned in that it adopts a constructivist perspective rather than a rational (as in *rational actor*) perspective. Table 1 provides an overview of its five elements. Figure 1 provides an illustration of the relationships among the elements. A more complete discussion of this framework was published earlier.[8] There are four key assumptions. First, a constructivist approach is advantageous due to the uncertainties and ambiguities that are inherent in any design problem. Simply put, a designer learns about the problem and identifies needs for additional data, information, and knowledge by trying to resolve the problem. That is, design involves learning by doing and then reflecting on what has been done. Second, that because there is no single solution to any design problem, the designer does not provide an uncontestable solution to a problem but makes an argument for change. The framework provides a basis to align interrelated assumptions for a consistent and coherent argument. Third, the role of an initial abductive conjecture or generative proposition is foregrounded in the use of the framework. An abductive conjecture is best guess answer to a, 'What if …?' question. It can be made in any of the five identified framework elements. Once made, the conjecture provides a foundation for specifying details in the other four elements of the framework. Fourth, subsequent design development occurs in two ways. 'Intensive design development' occurs as ideas within each of the five elements are refined. 'Extensive design development' occurs as relationships between the five elements are coordinated or aligned.

Framework Element	**What if … is/are changed?**	**Conventional form of representation**	**Emphasis of thought**
Image of the world	Core beliefs	Statements of facts and assumptions	Mysticism
Challenges•Opportunties	Transformable aspects of site and program	Context maps	Materialism
Vision	Comprehensive strategy to manage change	Metaphor	Idealism
Objectives	Available means to act for intended outcomes	Cause-effect models and systems diagrams	Pragmatism
Forms	Locations, dimensions, materials, and sequences of objects	Orthographic drawings, renderings, physical models	Realism

Table 1. Elements of the Framework

While extensive design development can occur when aligning any two elements, it is offered that alignments between elements that are adjacent to each other on the outer circle give rise to different kinds of philosophical considerations. The topics are labeled on the arcs in Figure 1, with a branch of philosophy on the inner side of the arc and a common-language expression on the outer side. This framework configuration has three implications. First, when following the diagram clockwise from Image of the World to Forms, the argument for change can be understood as going from general, more abstract propositions to specific, less abstract instances. In this direction, a prior element is put into practice or operationalized by a subsequent element. For example, the Vision, as a strategy to manage change, provides context for the ways individual Objectives, as topical ambitions, are defined to one another. Following the diagram counterclockwise from Forms to Image of the Work, the argument for change can be understood as articulating how a prior element features within a larger theme and, hence, to contributes to cultural meaning rooted in the Image of the World. For example, Vision calls upon fundamental media or practices of a kind of design problem identified in the Challenges•Opportunties. Second, each of the five elements serves as connection between two philosophical concerns. The role of Vision (expressed as a metaphor) to connect ethics and epistemology has been discussed in another paper.[9] Third and conversely from the second implication, each arc serves to connect two elements. Such a relationship is explored in this paper by way of the alignment between Objectives and Forms through aesthetics.

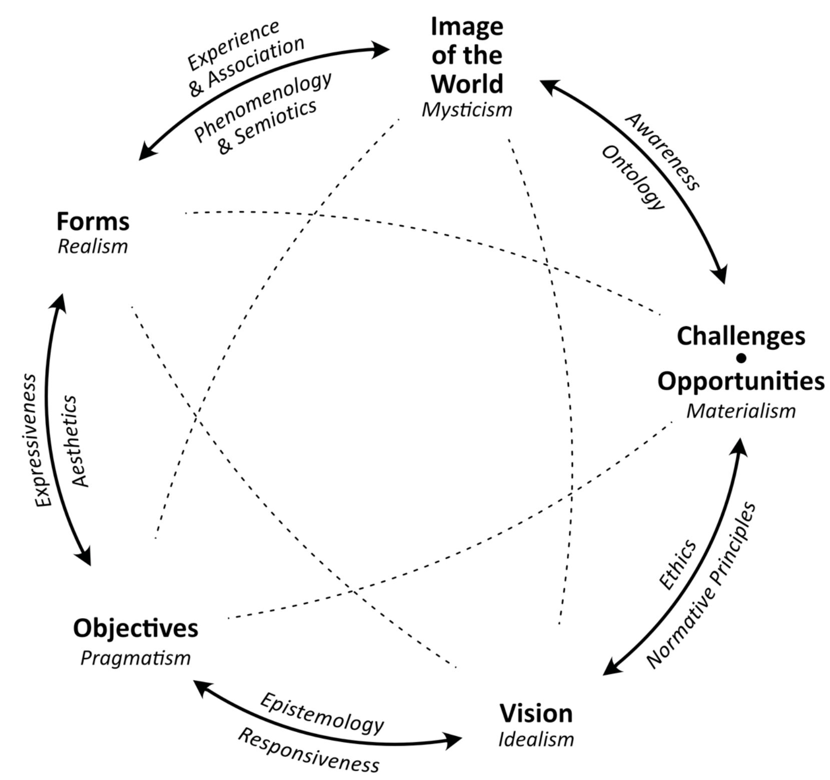

Figure 1. Constructivist framework for design (Source: Author. An earlier version of this diagram appeared in Allan W. Shearer, 'Abduction to Argument: A Framework for Design Thinking,' Landscape Journal *15:2 (2014), 130.)*

The conceptualization of aesthetics as used in this framework requires qualification. The study of aesthetics is understood broadly as considerations between the ways things present themselves and feelings. Often, aesthetics combined with criticism to posit ideas of beauty.[10] While this notion is applicable to the use of the framework, more than the form-making (compositional) talents of creators and connoisseurship of audiences are involved since, unlike a work of art in a gallery, environmental design must also address substantive health, safety, and welfare challenges. It can be readily accepted that considerations between form and function have been and are central to design, but rigorous discussions about these relationships are sometimes avoided. This situation is due perhaps to a concern related to the aphorism, 'beauty is in the eye of the beholder' and a desire to avoid professional debates based only on opinion or prejudice. Nevertheless, sensory appeals contribute to the reception of designed projects. Architect Lance Hosey has emphasized that appearance contributes to success and survival in both natural and in cultural setting.[11] Landscape architect Elizabeth K. Myer has commented the lack of discussions about aesthetics within larger discussions of environmental design can undermine sustainability goals.[12] Or, as art historian George Kluber has written the, 'merely useful things disappear more completely than meaningful and pleasurable things.'[13]

One author that provides a basis for thinking about aesthetics in this framework is Russel Ackoff, who was a scholar of business management. Writing on general problem solving, he identified four areas of knowledge and endeavor that provide a basis for human agency (and at an extreme, the pursuit of omnipotence to improve one's world).[14] The first requisite concerns understandings of science to improve capabilities and capacities to act with efficiency. The requisite concerns political economy and an ability to access the resources needed to make change. The third requisite is ethical and moral to reduce conflict among competing factions. The fourth requisite is aesthetic and concerns the ability to imagine ever new possibilities for improvement. Ackoff's description of the last requisite is built on the role of the arts to inspire and on the shared use of the phrase, 'it's beautiful' to describe both great works and innovative solutions to problems.[15] With regard to the topic of the present paper, the lesson from Ackoff is that considerations of aesthetics can be outwardly and collectively purposeful ideations for the future and not (only) inwardly and personally reflective examinations of the present or past.

A second author that provides a basis for thinking about aesthetics in this framework is the philosopher Jacques Rancière. While he begins with the recognition that aesthetics concerns outward appearances, he continues his exploration in terms of politics.[16] Central to both art and politics are logics and questions about how things in the world are shared and divided, distributed and re-distributed. That is, in this approach, art includes conventional works of art, but also extends to expressions of governance and the ways problems are assessed and addressed over time and space. For Rancière, a general regime of art combines 'modes of production of objects or the interrelation of actions; forms of visibility of these manners of making or doing; and the manners of conceptualizing or problematizing these manners of making or doing and these forms of visibility.'[17] The interplay of the three factors creates a basis for what is conceivably possible to create and what is recognizable when presented. Kluber employs a relatable but different logic to understand evolution of artifacts, but both he and Rancière seem to recognize that a given present moment will have its own aesthetic potentials and limits. These guides are in effect until larger factor changes. Like Ackoff, Rancière positions aesthetics in relation to other activities. His emphasis on the political, though, foregrounds considerations on the various rights and responsibilities of different members or kinds of members in a polity to participate. In this light, aesthetic propositions or postures contribute to the ways, means, and ends envisioned to change existing conditions into preferred ones with respect to differences of groups within a society.

Using the ides of Ackoff and Rancière to establish a provisional basis to consider aesthetics as contributing substantively (as opposed to only decoratively) to design (as opposed to art) compositions, the next part of this paper antifragility as a normative objective and the kinds of knowledge and interrelation of actions that might be taken to achieve it.

ANTIFRAGILITY

The term 'antifragility' was coined by Nicolas Nassim Taleb to describe systems that improve when exposed to volatility.[18] As introductory examples, he distinguishes antifragile from fragile and robust systems based on the potential effects of uncertainty using characters from Greek mythology. Fragile systems, like Damocles under the sword, have great exposure to loss due to uncertainty and do not benefit from exposure to it. Robust systems, like the Phoenix that rises after death, resist harm from uncertainty, but have limited gains from it. Antifragile systems, like the Hydra, are systems that grow or otherwise benefit from exposure to damage. The concept of antifragility has been examined in diverse contexts including business,[19] computer science,[20] international security,[21] logistics,[22] psychology,[23] and sustainable development.[24] The concept is also being applied to urban planning and design.[25]

A defining characteristic of antifragile systems is not only can their capabilities and capacities to manage disruption improve to manage experienced disruptions, but they can also develop abilities to manage those not previously encountered or, perhaps, even imagined. An example is person who exercises regularly is an example of an antifragile system: the body undergoes a temporary metabolic shift as it moves faster or for longer periods of time and as it employs different muscle groups to lift heavy objects. Through such training, the body becomes more fit and able to do some things that were not explicitly undertaken—including things that were not anticipated when the exercise plan was created. As such, antifragility is a distinguishable quality (or goal) from systems that are (or intended to be) sustainable or resilient. It has been debated if sustainability is a component of resilience or if resilience is a component of sustainability or if they are distinct concepts.[26] For this paper, differences are understood in terms of the kinds of uncertainties each approach emphasizes. Sustainability focuses on the long-term conservation of resources needed to maintain a system. With regards to environmental design, it considers the 'triple bottom line' of balancing environment, equity, and economics in such a way that does not reduce resources for future generations. This balance involves moral or ethical uncertainties.[27] Resilience concerns a focus on abilities to withstand, recover, and adapt from external shocks and becomes increasingly important as a system's internal organization becomes more complex and as its exchanges with the system's environment become uncertain or volatile.[28] With resilience, epistemological questions related to knowledge production about vulnerabilities and threats for purposes of governance.

The difference between antifragility and both sustainability and resilience can be exemplified by vaccination. The introduction of a harmful, but weakened or neutralized pathogen or mRNA (like some COVID-19 vaccines) into a body allows a person to develop resistance to stronger doses of the same pathogen in the future. So, a flu shot in the autumn helps prevent contracting flu in the winter. The same shot, however, does not protect against measles. With antifragility, attention shifts from resilience's epistemological uncertainty and questions of exposure rates and potencies to questions of ontological uncertainty related to unknows in the environment and possible interactions of unknowns with the composition, organization, and behavior of the system. Succinctly, becoming more antifragile is not adapting to handle the same sort of crisis better, but to better handle crises in general. Figure 2 illustrates these relationships.

Urban system qualities that contribute to antifragility include being emergent rather than resultant, risk allowing rather than risk averse, enabling small-scale rather than system-wide experiments, even rather than uneven distribution of resources, redundancy rather than efficiency, loosely rather than tightly coupled components, and variety and variability rather than uniformity.[29] Also, urban systems can exhibit nonlinear dynamics, reciprocal feedback loops, time lags, heterogeneity, and surprises. These qualities combine to create uncertainty and volatility that can allow for the emergence of both positive outcomes and negative outcomes.[30] While these qualities can support conditions that allow antifragility to develop, it is also possible to diminish the possibility by actions that contribute to fragility. These can include top-down actions that inhibit flexibility through extensive standardization or that pursue optimization of narrowly defined societal ends. An example in urban planning is strict zoning regulations. James C. Scott has written about such actions at the nation-state level.[31] Instead, actions or the interrelations of actions to support antifragility include loosely coupled sub-systems, redundancy, and a willingness to fail at small-scale experiments. Borrowing from studies in biodiversity and landscape ecology,[32] antifragile urban environments can be understood as being advanced through variety and variability at multiple scales.

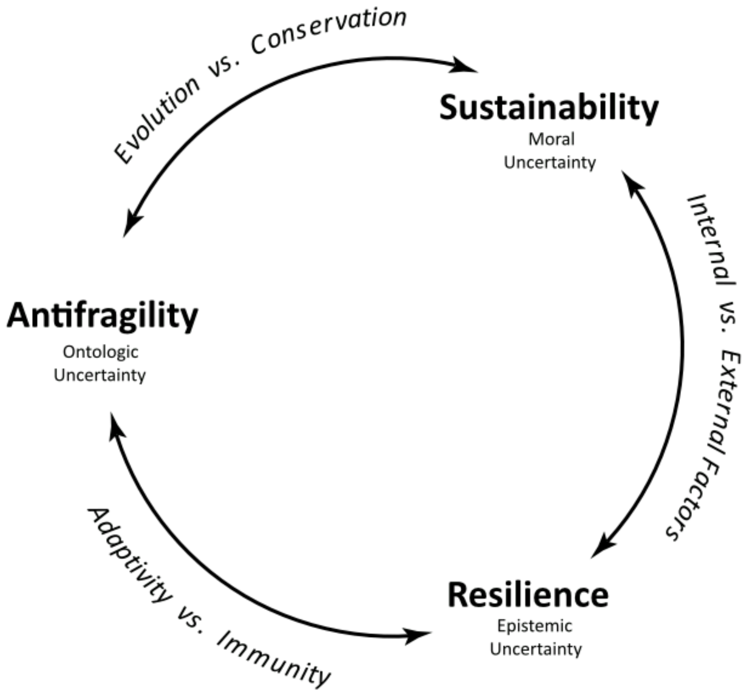

Figure 2. Comparison of concerns among sustainability, resilience, and antifragility (Source: Author)

TOWARDS AESTHETICS OF ANTIFRAGILITY

Accepting the premises given above, in what ways can antifragility be presented so that it is recognized as antifragile? Possible answers are not to provide a basis for a semiotics of antifragility, although that might one day develop as it has in other aspects of environmental design.[33] Instead, it is to help planners and designers envision forms that are supportive of the larger objective of antifragility as they work iteratively to structure ill-structured problems and make arguments for change.

An example of such a form can be seen in the mass transit system of London which includes busses, subways, and overground trains. Taxis and other rideshares along with increasing dedicated bicycle lanes add to the system. Several major stations, including Kings Cross-St. Pancrass, Liverpool Street, and Paddington along with several smaller hubs, provide interconnection across the modes of movment. The system has sufficient flexibility that riders can choose their route with great flexibility. A Transport for London study tracked mobile phone signals and found that riders between Kings Cross-St. Pancras and Waterloo used over eighteen different routes.[34]

How can such a configuration be described as part of an aesthetic? Heinrich Wolfflin's distinction between classical and baroque styles in *Principles of Art History* is offered as providing a first step.[35]

To Wolfflin classical art is linear ('draughtsmanly'), planar, closed form, composed of assembled multiplicities, and being compositionally clear. An example is the façade of the Palazzo Madama in Rome. Each window is, itself, a total compositional which is assembled from smaller compositions. None of the component parts are in anyway intertwined with others. Removing a window would result in a hole, but the logic of the design could be recognized and imagining the repair would be straightforward. Baroque art, by contrast is painterly, recessive, open form, a unity (parts are not distinguishable, and is only relatively compositionally clear. An example is the Spanish Steps, also in Rome. Foreground elements recess into near-background elements. The composition cannot be grasped in a glance since not all parts are visible from a single vantage. Understanding how to replace a removed part of the composition would not be straightforward. The London transit system dwarfs the size of the

Spanish Steps and every other baroque project described by Wolfflin, but there are similarities with regards to understanding that the whole is more than the sum of its parts.
To be clear, the use of Wolffloin's book to discuss 21st century design has limits. It is an old text, first published in 1915 and can be faulted for focusing only on style with little regard for historical contexts and offering only binary oppositions. It is also about art, not design so health, safety and welfare concerns are not engaged. These weaknesses are acknowledged, but task at hand is to identify some defined terms of compositional description that can be of value (and eliminate those that are not). If discussions about antifragility as normative proposition are to advance, approaches to describe possible forms are needed. Wolfflin may not be the answer, but can help to envision one.

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TOWARDS ENVIRONMENTAL JUSTICE: INTEGRATING SOCIO-DEMOGRAPHIC DATA FOR URBAN HEAT VULNERABILITY MAPPING

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INTRODUCTION

Climate change has a significant influence on extreme events, including increasing the intensity and frequency of heat events, which are detrimental effects to both the environment and human populations. 2022 was the warmest year on record in the United Kingdom, with temperature records being broken in multiple towns and cities including Cambridge (38.7 °C).[1] As urbanisation further intensifies heat extremes, it has been argued that urban areas are subject to particular heat risks and that cities must take immediate action to protect their residents.[2] However, the inequality of social and economic conditions in cities may unevenly increase heat effects, which can link to urban climate injustice.[3]

The objective of this research is to evaluate the spatial patterns of heat vulnerability, taking socio-economic and environmental factors into account. This research includes three primary vulnerability indicators, which are derived from a well-recognised approach using exposure, sensitivity, and adaptive capability. It is worth noting that the susceptibility to heat and social sensitivity might potentially be impacted by many factors specific to each location. This paper targets two cities in the United Kingdom for comparison, which are Milton Keynes and Cambridge. The latest census data released in 2022 serves as socioeconomic input in constructing heat vulnerability indices, combined with satellite imagery.

HEAT THREATS

Records show that heatwaves appeared more than in the last century.[4] According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, the frequency, duration and intensity of hot extreme weather have increased since 1950.[5] The frequency, duration and intensity of heatwaves in the United States since the 1960s also illustrate the same phenomena as the global trends (Figure 1).

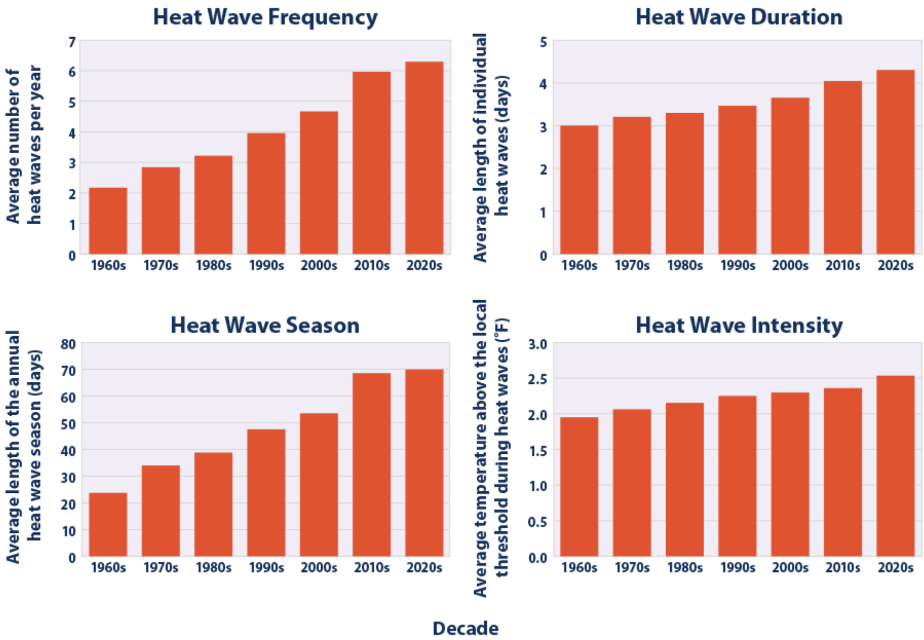

Figure 1. Heatwave Characteristics in the United States by Decade, 1961–2023 (Data source: NOAA, 2024[6])

It is predicted that heatwaves will continue to increase in intensity, frequency and duration in the future.[7] Undoubtedly, this is a concerning occurrence, as the negative health effects induced by excessive heat pose an immediate danger to human health. According to previous records, cases of heat-related death and mental illness increased during extreme heat events.[8] In the published heat mortality monitory report published by the UK Health Security Agency (UKHSA), there were an estimated 2,985 all-case excess deaths associated with five heat episodes, which was the highest number in the given years.[9] Therefore, increases in heat deaths related to climate change have drawn attention to actions that can be taken to reduce risk, and have highlighted the importance of identifying areas and populations that are at potential risk.

Environmental Injustice in Heat Effects

Different factors influence the scale of heat vulnerability, including socioeconomic, demographic, health, land cover, and temperature determinants.[10] In urban areas, the Urban Heat Island Effect (UHIE) has become more severe with rapid urban sprawl and development.[11] Land cover patterns and urban forms contribute to how urban areas are exposed to heat effects, and how UHIE varies across spaces. For example, the physical size of the city,[12] its landscape heterogeneity,[13] population and building density,[14] are associated with the temperature in cities in diverse ways.

Various social and demographic factors also influence the levels of heat threats within populations. Specific groups of the population such as the elderly and young people are at higher risks of physiological conditions, and are particularly sensitive to heat effects.[15] This susceptibility also varies across ethnic groups, such as African American or Black ethnicity groups and disadvantaged communities are seen to be located in higher heat vulnerability areas in a case in the United States.[16] Additionally, disparities in income may increase the risks of heat effects due to the difficulty of adaptation. Although buildings in some places are equipped with air-conditioning, rising energy costs also leave economically disadvantaged households in a difficult situation. This kind of 'summer energy poverty' causing heat vulnerability in populations has been seen in Madrid and London.[17]

Green Infrastructure and Environmental Injustice

Green Infrastructure has been advocated as a strategy to adapt to the effects of extreme heat in urban settings, with recognition of the advantages provided by these green spaces.[18] These assets including street trees, multiple scales of parks, and lakes create shade and cooling effects to reduce the temperature during hot summer days. However, when greening actions have been advocated as adaptation strategies to extreme heat, practical cases suggested a more tangible design for risk reduction, as the disparity between ecosystem services and social conditions increases inequality[19] A critical challenge is to avoid greening strategies in the name of sustainability contributing to gentrification. A 'just green enough' approach may be contested to be implemented in urban areas, as it is found that these assets towards sustainability are constructed in gentrifying neighbourhoods,[20] while economically deprived areas lack sufficient cost-benefit strategies as green infrastructure designed to cope with heat effects. Nevertheless, these vulnerable populations usually have to bear with environmental injustice such as less coverage of green spaces and face high energy costs in this imbalanced situation.[21]
While environmental hazards are often spread unevenly throughout societies, it is important to recognise the discrepancies in risk exposure, risk reduction, and risk adaptation. These imbalances highlight the significance of justice in preventing increasing threats to vulnerable people. These features above reflect the strong connection between environmental justice and heat effects driven by social inequity. Identifying areas with this potential risk is crucial for avoiding injustice.

INTEGRATE SOCIAL-DEMOGRAPHIC DATA IN HEAT VULNERABILITY MAPPING

Resolving the situation whereby some people are more vulnerable to heat effects means addressing the issue from various aspects. Creating an integrated index to include social demographic characteristics is vitally important to identify the areas with potential for environmental injustice. Therefore, this study acknowledged previous work in constructing a composite index with indicators of exposure, sensitivity and adaptive capacity.[22] These three aspects respectively cover the physical environmental characteristics, specific demographic conditions that are vulnerable to heat risks, and the capacity to adapt to heat stress through green infrastructure provision. Figure 2. shows the variables included in each category.

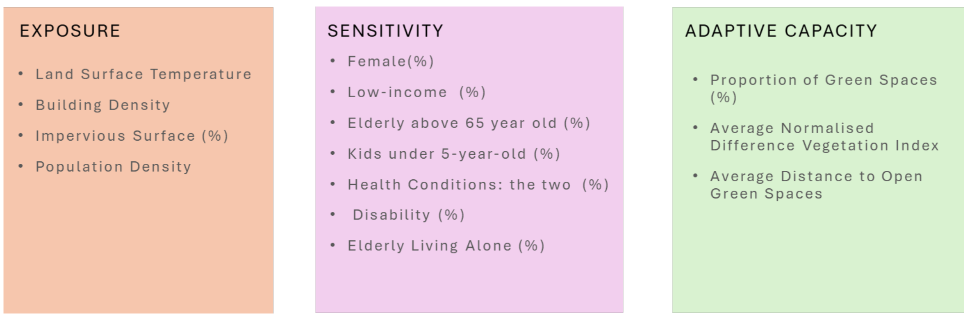

Figure 2. Variables in the three categories of heat vulnerability mapping

Several works worldwide acknowledge the importance of the connection between social vulnerability and climate hazards, and they have considered individual social conditions to assess environmental effects.[23] Principal Component Analysis (PCA) is one approach to social-related vulnerability mapping, including studies evaluating vulnerability at census area level in Malaysia, the United States and Korea.[24] The application of PCA reduces dimensionality within the assessment process, which facilitates the extraction of more significant components and can best explain the co-variability of the data. It further enables a more comprehensive targeting of vulnerability levels. In terms of heat vulnerability mapping, this includes concerns about the extent of how the population can behave to be resilient to disasters and natural hazards.[25]

Therefore, this research applies this assessment approach to integrate social-demographic and socioeconomic data into environmental indices, to acknowledge factors that may influence heat vulnerability. For heat vulnerability assessment, it can also represent the intra-urban variation of heat risk and comprehensively consider the variation of social and environmental conditions, in particular at a more detailed spatial scale within the urban area.

Study Areas

For the UK, a previous study developed the heatwave vulnerability index for London based on the census data in 2011,[26] yet the assessment of the latest census data has not been undertaken after the extreme heat event in 2022. In contrast to previous cases, this study aims to select two cities in the UK that possess distinct characteristics in the comparison, taking respectively an old and smaller city (Cambridge) and a newly developed green city (Milton Keynes) into account, as these two cities possess different social characteristics and urban forms, but both with large coverage of green spaces.

Cambridge is a small city located around the banks of the River Cam. This city is well-known for its research, education, and knowledge-based enterprises, and possesses substantial historical background. It covers an area of 40.7 km^2 and encompasses a population of 621,200. According to the statistics from the City Council, this city boasts 743.59 hectares of Protected Open Space (POS), including green commons and parks and gardens owned by Cambridge University. This amounts to around 6.2 hectares of protected open space per 1,000 residents, of which 2.9 hectares per 1,000 persons are available to be publicly accessed. This city suffered heat issues during the past years and the heatwave in July 2022 surpassed the earlier record (new record as 38.7 °C) and was far more intense than those previous years. In addition, the uneven distribution of accessible green spaces and socioeconomic inequality may bring larger challenges to this city.

Milton Keynes is a relatively new city built during the late 20th century. It is in Buckinghamshire, approximately 72 km from London. It covers about 89 km^2 of area size with almost 6,000 hectares of green spaces. 270,200 people are living in this city, and the ratio of elderly people accounts for 20%. It has been ranked as the top local government in terms of open space per citizen and has been perceived as one of the greenest cities in the UK.[27] This 'manmade' city is planned under the concept of the Garden City, which attempted to construct a metropolis with an emphasis on green belt regions and population management. A unique urban form consisting of green grid carriageways dividing the city into sub-defined neighbourhoods is also seen in Milton Keynes. However, some areas in Milton Keynes are among the most deprived areas in England in terms of building conditions and socioeconomic profiles[28], reflecting a high level of sensitivity to extreme heat events.

Data Sources and Calculation

This research first utilises an open-source platform: Google Earth Engine (GEE) for processing and downloading Landsat 8 satellite imagery for land surface temperature data acquisition.[29] The temporal coverage of data is between June to September 2022. These images are pre-processed with cloud masking and then used to calculate the average temperature to meet the same spatial scale as the social demographic data. The green infrastructure index of the Normalised Difference Vegetation Index (NDVI) is also acquired through GEE. Pixels indicating NDVI values larger than 0.2 are considered as green spaces and used to calculate the green coverage in each tract. The data on Open Green Spaces released by the Ordnance Survey is later used to calculate the distance from settlements to these open green spaces, which indicates the accessibility to cooling infrastructure.

For other selected variables, the latest census data released by the Office for National Statistics with the scale of the Lower Layer of Super Output Area (LSOA) is used to serve as social demographic indices, and the socioeconomic status then relies on the sub-index of income rate in the Integrated Multiple Deprivation Index (IMD). However, due to several census boundaries being updated and merged during the investigation, social information with the nonmatched codes of geography boundaries and census data may be seen in the original datasets. These areas with missing data and mismatched information are neglected before PCA analysis.

Steps for PCA operation are shown below in Figure 3, following the standard processes in previous studies.[30] For the first step, the Kaiser-Meyer-Olkin test and the Bartlett test are employed in the analysis process to check the suitability of PCA employment, and the number of reduced components will be determined by the Kaiser Criterion (eigenvalue larger than 1). The resultant principal components (PCs) are new orthogonal variables ordered by the amount of variance they represent in the data, and varimax rotation was used to enhance the interpretation by supplying each variable with a single component to maximize the dispersion of loadings across the PCs. The rotated PCs are used to weigh the reconstructed indicators in each category (exposure, sensitivity and adaptative capacity) before aggregation, and normalised to the index between 0 and 1.

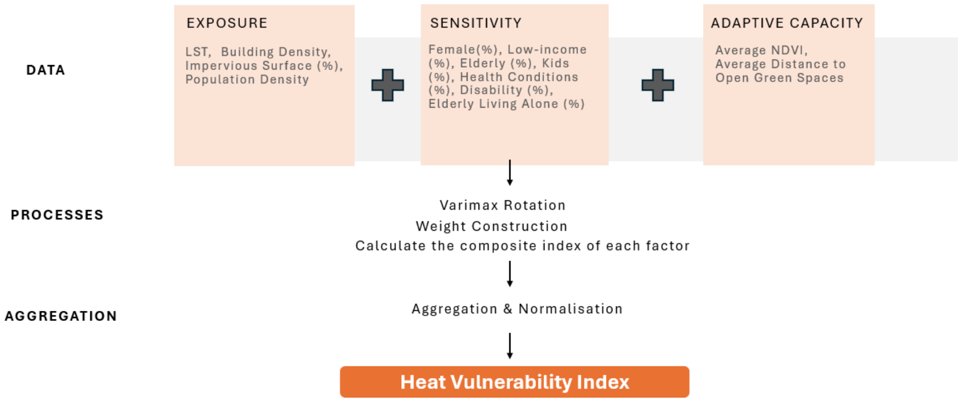

Figure 3. Operation of PCA for heat vulnerability calculation.

FINDINGS

This section discusses the extracted principal components and then compares the analysed results in Milton Keynes and Cambridge.

What are the principal components in driving the heat vulnerability indicator?

Five principal components passed the Kaiser Criterion after PCA extraction. On average, these five factors for HVI mapping accounted for 68.5% of the variance in the data. In each component, the variables contribute to different levels of factor loadings, which are shown in Figure 4. The first component represents variables describing environmental characteristics, while the second describes variables of age and isolation. It is seen that the variables loaded onto the second and third factors are across vulnerability representatives. Variables indicating minority status, such as income and being physically disabled, consistently load together. Other components describe the accessibility to green spaces and the urbanicity characteristics of buildings with a higher density. The green infrastructure variables are loaded in the negative status with minority and socioeconomic status, indicating that a higher percentage of the socially vulnerable population occurred in the area with less green coverage.

As the temperature indices vary in the same direction as socially vulnerable variables, it also indicates that these populations are located in hotter areas, which increases the potential heat risks.

Figure 4. Factor loadings for PCA outputs

A Comparison between Cambridge and Milton Keynes

After normalising in the final step of HVI analysis, the integrated HVI in Cambridge and Milton Keynes are shown in Figure 5 below. It is seen that HVI patterns distributed unevenly across spaces and scales, and larger areas are generally with lower HVI values. The differences in HVI value can be easily recognised through distinct colour hues. Most areas in both cities show intermediate levels (yellow and orange colours), but a few regions indicate higher heat vulnerability with dark red on the map. A total of 3 areas in Cambridge and 5 areas in Milton Keynes are classified in the most vulnerable category. In Cambridge, these regions with greater HVI are predominantly situated in the eastern part of the city, and the top-ranked heat-vulnerable area is in the northeast, largely based on the density of the built environment. Conversely, in Milton Keynes, high HVI areas are primarily concentrated in the central southern region and exhibit a clear linear pattern in the middle, yet the influencing factors are based on social deprivation indicators.

Upon investigating these high HVI locations, it is discovered that different variables have contributed to the disparity in HVI between these two cities. In Cambridge, the number of buildings and impermeable surface proportion is higher in the eastern areas of Cambridge, which leads to increased vulnerability. Other lower HVI areas are census tracts with larger sizes, meaning a lower population density, and a smaller amount of impermeable surfaces. The western areas of Cambridge are in close proximity to expansive meadows held by the University Colleges, also showing a lower HVI on the map. However, these meadows are not easily accessible to the general public. This phenomenon has shown inequality towards environmental injustice in this case.

A significant proportion of the green areas in Milton Keynes are shown to enhance the adaptive capacity factor positively. The presence of extensive green infrastructure, such as Ouzel Valley Park, has reduced the vulnerability of these places, as clearly seen on the map located adjacent to the linear red pattern. Nevertheless, as stated in the beginning, several neighbourhoods of Milton Keynes are considered the most deprived in England when it comes to the condition of the buildings. This phenomenon has resulted in a high HVI index in the centre southern part of the city. Neighbourhoods such as Coffee Hall and Netherfield are characterised by low-rise detached dwellings with one or two storeys (shown in Figure 6). These districts had rapid development following World War 2 to accommodate inhabitants from London, but the houses nowadays may not be resilient to extreme heat effects. Therefore, social economic and vulnerability components are seen as more principal to result in heat vulnerability in Milton Keynes, according to what is shown on the map.

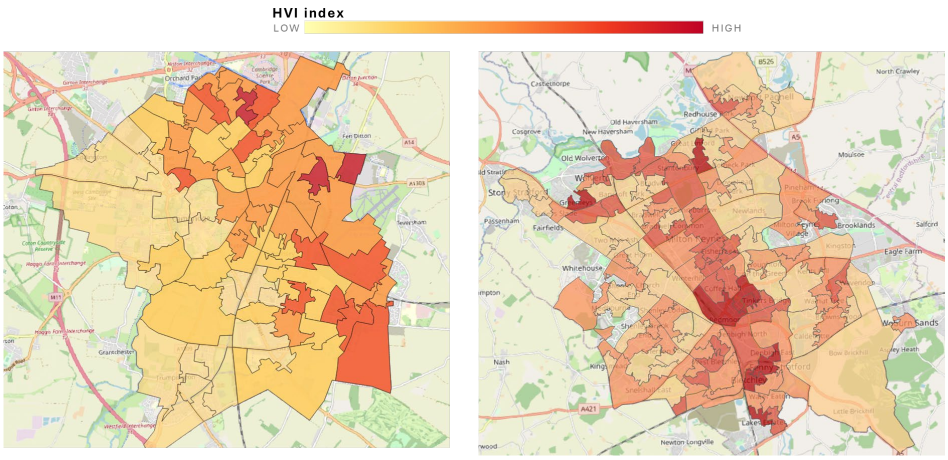

Figure 5. Social-related heat vulnerability map in Cambridge (left) and Milton Keynes (right).

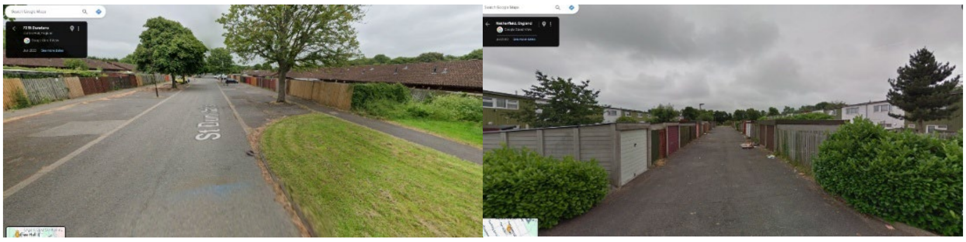

Figure 6. Google Street View of Coffee Hall (left) and Netherfield (right).

DISCUSSION

Towards Environmental Justice: What's next?

Through a comparison of these two cities, it becomes evident that the factors contributing to heat vulnerability are dependent on the individual circumstances of each location. Furthermore, the assortment of primary factors that lead to heat vulnerability also differs between these two instances, suggesting the need for distinct remedies in the future. Cambridge should evaluate the equilibrium between the quantity and availability of green areas inside the city, whereas Milton Keynes should prioritise addressing socioeconomic inequality to develop practical solutions.

Once the recognition of the difference in heat vulnerability is acknowledged, strategies for adjusting to changing circumstances can be tailored according to the distinct characteristics of social and environmental factors. In light of the increasing heat risks, it is also worth exploring if additional measures are being implemented to mitigate climate change through greening initiatives. It is essential to also examine the internal dynamics inside these vulnerable communities to identify any local efforts that may arise to assist the local population. From the standpoint of resilience, it is necessary to engage more stakeholders in deeper conversations to explore what can be improved. This will help uncover how policy implementation and research may effectively assist local communities in achieving a more favourable future.

CONCLUSION

This study provides an example of how social characteristics can be integrated into heat vulnerability mapping in the UK. The results reinforce the idea that drivers of heat vulnerability are very context-specific. Social-related heat vulnerability appears differently between these two UK cities. Researchers and decision-makers are recommended to further consider regional disparities before implementing adaptation strategies.

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INFLUENCE OF STREET TREE DYNAMIC GROWTH ON PEDESTRIAN THERMAL COMFORT: A CASE STUDY OF HARBIN, A FRIGID CITY

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INTRODUCTION

As global temperatures rise, urban areas are experiencing more frequent and severe summer heat waves. These extreme conditions expose pedestrians to dangerously high temperatures, posing significant health risks. In addition to increasing the likelihood of heat stroke and fainting, these conditions may also elevate the risk of heart disease and exacerbate respiratory problems.

Urban street morphology influences the thermal comfort of streets by altering the duration of direct sunlight. In response to the impact of street morphology on climate, Oke et al. proposed a theory to modify the regional microclimate by adjusting block layouts and controlling the block canyon layer.[1] Currently, the primary method for studying how urban streets affect thermal comfort involves the use of street geometry indicators. Among these, the sky view factor (SVF),[2] street aspect ratio, and street orientation were initially employed and remain widely utilized.[3] Research on the role of vegetation in enhancing the thermal comfort of urban street spaces suggests that the impact of vegetation primarily depends on plant morphological characteristics and planting patterns.[4] Studies examining the correlation between vegetation morphology and the urban thermal comfort focus on factors such as plant species, trunk height,[5] tree height-to-width ratio,[6] crown morphology,[7] leaf area density (LAD) ,[8] leaf area index (LAI) ,[9] and other plant-related indices. Additionally, research on the correlation between planting patterns and the urban thermal comfort highlights the significance of plant number,[10] arrangement,[11] spacing,[12] configuration, and other plant-to-plant indices.[13] Vegetation influences the thermal environment of streets primarily through cooling and humidification mechanisms. The cooling effect is mainly derived from tree shading,[14] while humidification occurs through water release via plant transpiration. Vegetation reduces the energy reaching the ground by blocking shortwave solar radiation,[15] thereby lowering the air temperature in the street and increasing the relative humidity of the surrounding environment through transpiration. As water evaporates, the surrounding air temperature decreases.

For built urban blocks, vegetation is the most effective measure for regulating thermal comfort in street canyons. Vegetation reduces thermal radiation and increases humidity through shading and evapotranspiration. Because vegetation undergoes dynamic growth, different stages of its life cycle have varying impacts on improving thermal comfort. Thus, we examine its effects on street thermal comfort from a life cycle perspective.

Therefore, this study uses Harbin, China, a severely cold city, as a case study to examine the impact of street tree growth on thermal comfort through field measurements and numerical simulations. Using ENVI-met software to simulate experimental groups of trees at different growth stages, the study clarifies the impact mechanisms between street tree growth and thermal comfort. This provides theoretical support for developing efficient, accurate, and cost-effective street tree renewal strategies.

METHOD

This study focuses on Harbin, a cold city in China. As a crucial hub of the China-Eastern Railway, Harbin's street layout is significantly influenced by the railway and the Songhua River, resulting in an overall NE-SW orientation of 45°. The typical street form of Nangang District was selected as the research object, as illustrated in Figure 7. A typical residential block with a representative height-to-width ratio for Harbin was chosen, including three NW-SE oriented streets and three NE-SW oriented streets, to study the impact of tree growth on the thermal comfort of street pedestrians.

The selected street canyon groups share similar basic characteristics: the underlying surface material is consistent, with asphalt roadways, red-brick sidewalks, and buildings predominantly 5-8 stories high, as detailed in Table 1.

China | Harbin, Heilongjiang Province | NanGang District

Figure 7. Study area

Name	Orientation	layer	Width	H/W	Substrate material
Yaojing Street	NW-SE	5-6	33.6	0.75	Asphalt, Red Brick
Fuhua Street	NW-SE	6-8	23.5	0.92	Asphalt, Red Brick
Fuxing Street	NW-SE	6-7	35.8	0.66	Asphalt, Red Brick
Fanrong Street	NE-SW	5-7	25.6	0.82	Asphalt, Red Brick
Fuhuasandao Street	NE-SW	5-7	24.2	0.74	Asphalt, Red Brick
Fuhuasidao Street	NE-SW	6-8	29.8	0.75	Asphalt, Red Brick

Table 1. Street canyon characteristic parameters

In terms of tree species selection, this study focused on the three most common and widely used street trees in Harbin:Ulmus pumila, Populus alba, and Salix matsudana. The research included newly planted, middle-aged, and mature specimens, corresponding to 5-year-old, 15-year-old, and 30-year-old trees, respectively. The biological characteristics of these street trees, such as tree height, diameter at breast height (DBH), crown diameter, height under branches, and leaf area index (LAI), were measured using a rangefinder, a plant canopy analyzer, and a tape measure, as shown in Table 2. These tools were used to obtain the average values for the biological characteristic parameters of the three tree species at each growth stage. The age data for the street trees were obtained from official government records. Crown diameter measurements were taken from four directions at the center of the tree, with the average value calculated to determine the crown diameter.

Measuring instrument	Parameter	Range of measurement	Instrument precision	Instrument image
Distance measuring equipment	Distance	0-800m	±0.5m	
Tape measure	Distance	0-20m	±0.5cm	
Plant canopy analyzer	LAI	-	-	

Table 2. Measuring instruments and parameters

Cho Kwong Charlie Lam et al. (2021) reviewed 130 articles related to outdoor thermal comfort using Google Scholar and Web of Science, analyzing the various computer simulation software currently employed in outdoor thermal comfort studies.[16] Their analysis revealed that ENVI-met is used far more frequently than other software, with existing research demonstrating its strong applicability in cold regions. Consequently, this paper utilizes ENVI-met to simulate the impact of street tree growth on the street thermal environment.

ENVI-MET VERIFICATION

This study compares the measured values of the block with the ENVI-met simulation results to verify the accuracy of the software. Field measurements were conducted to obtain air temperature and relative humidity data for each street at 30-meter intervals from 8:00 am to 6:00 pm. The measurement results are presented in Figure 8.

A block model was established in ENVI-met with dimensions of 696m × 723m × 188.82m. The model consisted of 232 × 241 × 25 grids, with a resolution of 3m × 3m × 3m. In the vertical direction (Z-axis), the resolution was set to gradually increase above 21m, with a scaling factor of 11%. The model's compass was rotated 39.94° clockwise to match the actual orientation. Vegetation was adjusted using SVF parameters to ensure consistency with the current situation. Weather station data from the day of measurement was imported into ENVI-met to simulate the thermal environment. The simulated and measured values of air temperature and relative humidity were then fitted, showing a slope of the fitting function and an R-squared value close to 1, indicating a high correlation, as shown in the Figure 9.

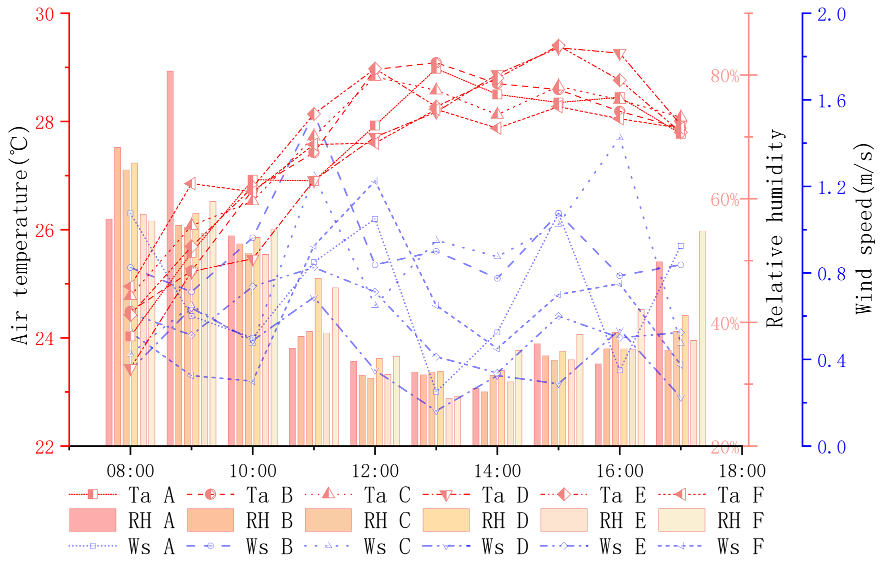

Figure 8. Measurement data

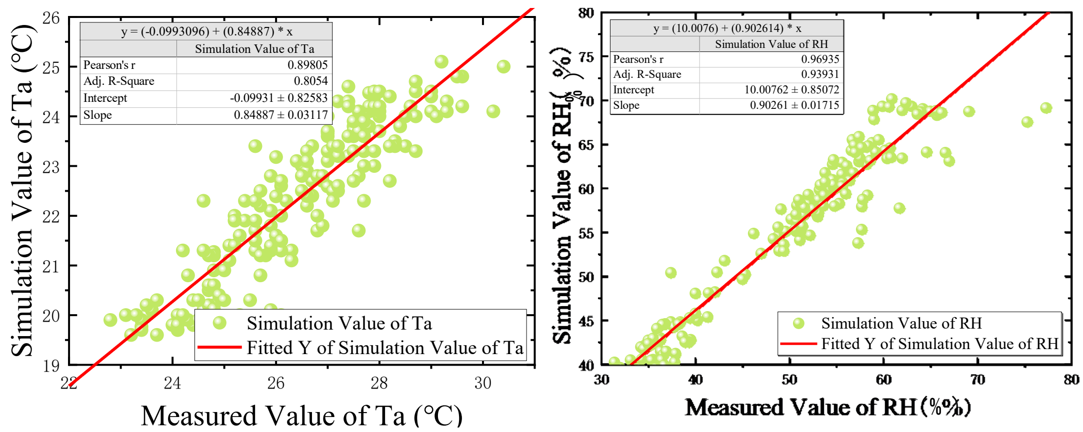

Figure 9. Correlation analysis of simulation verification results

EXPERIMENTAL SETUP

The sample blocks selected in study area were used as spatial carriers to establish a street canyon model using ENVI-met, as shown in Figure 10. Since the meteorological data were measured on September 5, 2021, the simulation was conducted using the measured block model as the spatial carrier. To ensure consistency, the simulation time was set to the same day.

On six streets in Harbin, four sampling points were established at equal intervals within each street canyon of the study block. Three tree species were planted along the NW-SE and NE-SW streets to simulate three different growth stages. As shown in the figure, the planting distance between trees was set at 12 meters. This study conducted four groups of experiments: one control group and three experimental groups with tree ages of 5, 15, and 30 years, respectively, to assess the impact of street tree growth on pedestrian thermal comfort, as shown in the Figure 11. The PET was selected as the evaluation index. The boundary conditions for the experimental group simulations were set identical to those used in the simulation verification stage.

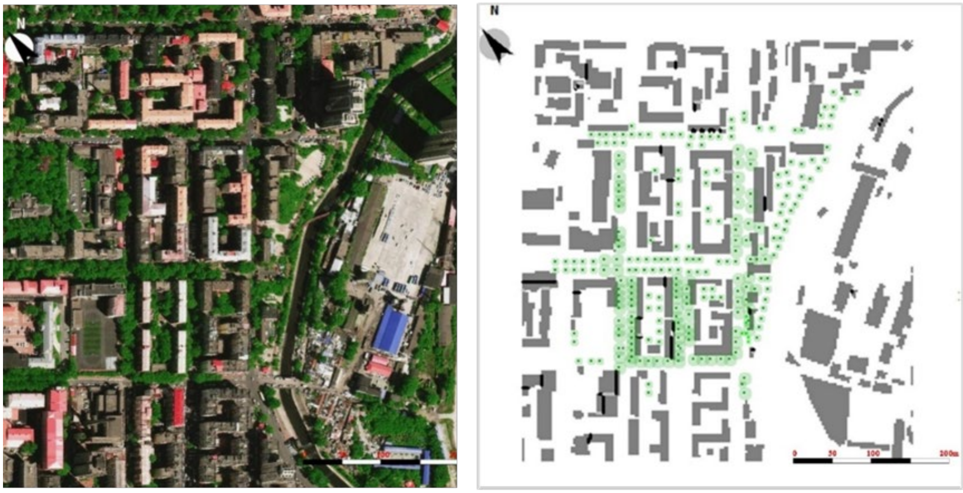

Figure 10. Models and satellite maps of the study area

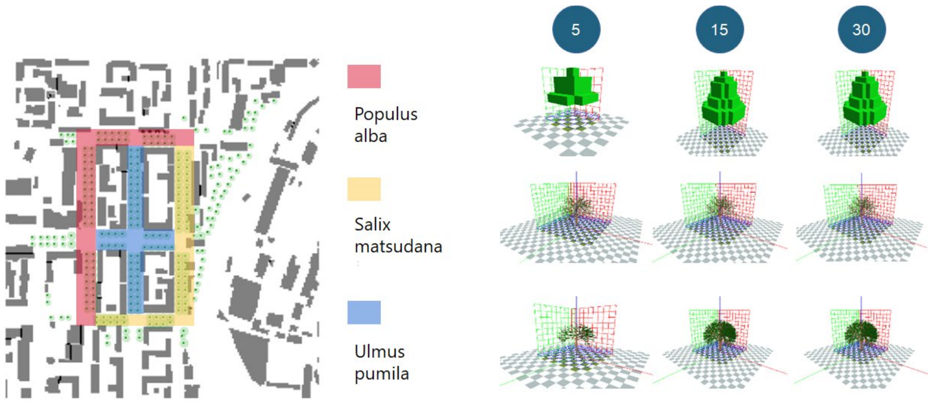

Figure 11. Experimental model

RESULTS

The Figure 12 shows the distribution of PET values from 7:00 am to 6:00 pm for NW-SE and NE-SW oriented blocks, with Populus alba, Ulmus pumila, and Salix matsudana trees at ages 5, 15, and 30 years, respectively. The figure indicates that the PET trends for each experimental group are consistent throughout the day. The PET value for the NW-SE street peaks at 11:00 am, while the PET value for the NE-SW street peaks at 1:00 pm. The difference in PET values varies with tree age, with the largest differences occurring at peak PET times. Additionally, the figure shows that when the PET value of the block reaches its highest peak, the 30-year-old Populus alba and Salix matsudana trees result in the lowest PET values, significantly improving thermal comfort. However, for Ulmus pumila, the cooling effects of the 30-year-old trees and the 15-year-old trees are similar, with the 15-year-old trees even showing the best cooling effect. This is because, as Ulmus pumila ages, its crown and Leaf Area Index (LAI) become larger, which obstructs air circulation and hinders heat dissipation within the block. Consequently, as the trees age, the PET value of the block initially decreases but subsequently increases.

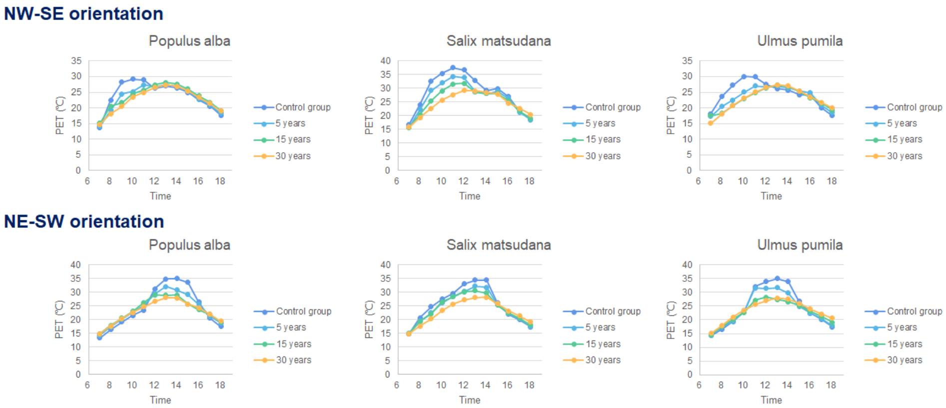

Figure 12. PET values from 7:00 am to 6:00 pm for NW-SE and NE-SW oriented blocks

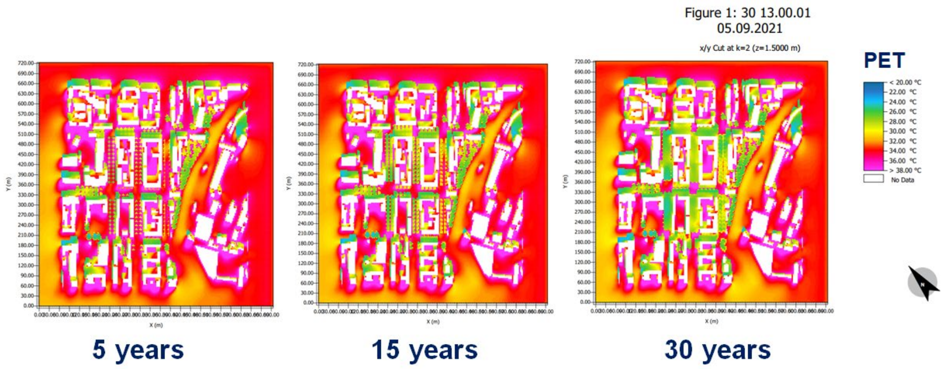

Figure 13. The PET value of Populus alba, Ulmus pumila and Salix matsudana exterimental groups at 1pm

The Figure 13 illustrates the impact of Populus alba, Ulmus pumila, and Salix matsudana on the PET index in the street canyon at 1:00 pm, the hottest time of the day, for trees at ages 5, 15, and 30 years. The PET spatial distribution map clearly shows that as the street trees mature, the PET value consistently decreases, with the block featuring 30-year-old trees exhibiting the lowest average PET value. The figure indicates that as tree age increases, the denser canopy provides a broader shade range, resulting in a lower average PET value for the entire block. This demonstrates that a denser canopy contributes to cooler conditions for pedestrians, highlighting the importance of mature trees in maintaining comfort during peak heat times.

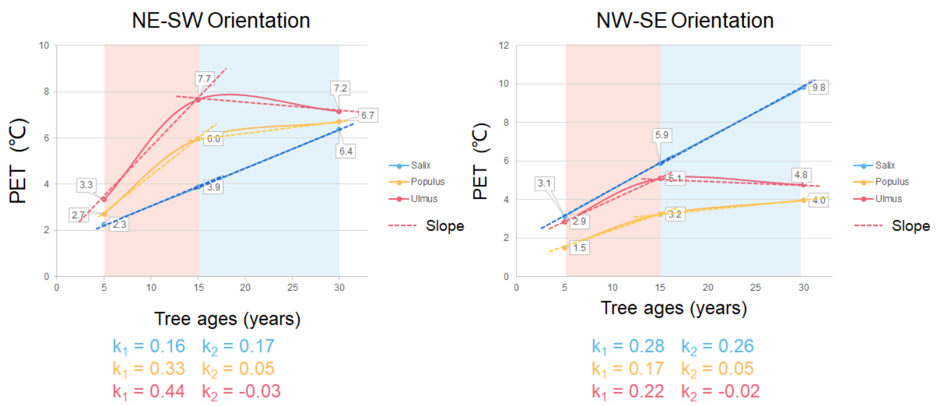

Figure 14. The maximum difference of PET between the three experimental groups and the blank control group

The Figure 14 illustrates the maximum difference in PET between the three experimental groups and the blank control group, highlighting the maximum improvement in thermal comfort achieved by each experimental group in the street canyon. The data shows that the PET trends for each tree species across different orientations are generally consistent.

Notably, in the northwest-southeast and NE-SW orientations, Salix matsudana, Populus alba, and Ulmus pumila achieved maximum temperature reductions of 9.8°C, 4.0°C, 5.1°C and 6.4°C, 6.7°C, and 7.7°C, respectively. Comparisons among tree species reveal that, in the NE-SW orientation, the 15-year-old Ulmus pumila tree provides the most significant improvement in PET values, while in the northwest-southeast orientation, the 30-year-old Salix matsudana demonstrates the most substantial reduction in PET. These results offer valuable insights for urban street tree renewal strategies.

Additionally, we analyzed the cooling slope of street trees at different growth stages. The slope of each segment in the function graph represents the rate of PET reduction, indicating the change in PET for each additional year of tree age. Generally, the slope from ages 5 to 15 years is steeper than that from 15 to 30 years. Specifically, during the 5-15 year stage, Ulmus pumila on NE-SW oriented streets has the largest slope ($k1 = 0.44$), meaning the PET value decreases by 0.44°C for each additional year of tree age. In comparison, the slopes for Populus alba and Salix matsudana are 0.33 and 0.16, respectively. Furthermore, the improvement in PET value at 5 years of age is highest for Ulmus pumila (3.3°C), compared to Populus alba (2.7°C) and Salix matsudana (2.3°C). Therefore, planting Ulmus pumila saplings in NE-SW orientations is recommended for the fastest improvement in street thermal comfort. In the 15-30 year period, the improvement effect of Ulmus pumila and Populus alba on thermal comfort slows, while Salix matsudana's impact on PET continues to increase with tree age. Trend predictions suggest that after 30 years, Salix matsudana will provide greater and more sustained improvement in thermal comfort compared to the other two species, making it the best choice for long-term benefits.

In the NW-SE oriented streets, Salix matsudana exhibits the largest slope ($k1 = 0.28$), meaning the PET value decreases by 0.28°C for each additional year of tree age. In comparison, the slopes for Populus alba and Ulmus pumila are 0.17 and 0.22, respectively. Additionally, at 5 years of age, Salix matsudana provides a PET reduction of 3.1°C, which is higher than that of Populus alba (1.5°C) and Ulmus pumila (2.9°C). During the 15-30 year stage, similar to the NE-SW (NE-SW) orientation, the improvement effect of Ulmus pumila and Populus alba on thermal comfort slows down, while Salix matsudana's effect on PET continues to increase with tree age and remains higher than that of the other two species. Therefore, in the NW-SE orientation, planting Salix matsudana is recommended for achieving a faster and more efficient improvement in PET values.

In both NW-SE and NE-SW orientations, the improvement in PET value due to Salix matsudana increases with tree age. This is likely because the leaf area index of mature Salix matsudana is relatively low, resulting in higher crown porosity. Consequently, the dense crown does not significantly impede air circulation within the street canyon. Instead, it provides enhanced shading and more humid air, which contributes to greater pedestrian comfort. Conversely, as the age of Ulmus pumila and Populus alba increases, the reduction in PET value due to decreased air velocity becomes more pronounced compared to the shading effect. This leads to a gradual decrease in overall thermal comfort.

CONCLUSION

Our study examined the impact of street tree growth on thermal comfort in street canyons. The results indicate that in the NW-SE and NE-SW orientations, Salix matsudana, Populus alba, and Ulmus pumila achieved reductions in PET values of up to 9.8°C, 4.0°C, 5.1°C and 6.4°C, 6.7°C, and 7.7°C, respectively. The PET spatial distribution map demonstrates that, at the peak temperature, the PET value consistently decreases with tree maturity, with blocks featuring 30-year-old trees showing the lowest average PET values. The improvement in thermal comfort is more pronounced for trees aged 5-15 years compared to those aged 15-30 years. In the NE-SW direction, Ulmus pumila exhibits the steepest improvement slope, making it advisable to plant Ulmus pumila saplings for rapid enhancement of street thermal comfort. However, after 30 years, Salix matsudana shows a more significant long-term improvement in thermal comfort. For the NW-SE orientation, planting Salix matsudana is recommended to achieve faster and more efficient reductions in PET values.

Nevertheless, this study has certain limitations. It focuses solely on the relationship between the growth of street trees and thermal comfort in street canyons, without considering park tree species. Additionally, the study examines only three growth stages of street trees, which may not fully represent the entire life cycle. Future research should aim to develop a comprehensive growth model that covers the full life cycle of street trees and establishes a detailed relationship between tree growth and PET values in street canyons. Expanding the research to include a larger scale would also provide more generalizable insights.

ACKNOWLEDGEMENT

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SECTION TWO

MAPPING SOLAR SOLUTIONS OF UNDER-RESOURCED LARGER TROPIC OF CAPRICORN AND GLOBAL SOUTH COMMUNITIES

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INTRODUCTION

How the Global South and the larger Tropic of Capricorn region communities and cultures respond to climate change varies significantly. These communities have contributed little to impacting factors but are directly affected by them. They share many similar challenges to their climatic and environmental conditions. Concerns for these vulnerable populations include socioeconomic circumstances, post-colonial cultural identities, and access to technology that impact housing shortages, food sovereignty, water, coastal and energy insecurity, and environmental imbalance. We are investigating and mapping how we can make connections between similar-enough solutions to support vulnerable communities across the larger Tropic of Capricorn region.

We began by mapping the physical location of solar projects. We did this to examine how communities adapt local, global, traditional, indigenous, and contemporary technologies. The focus is on finding examples of efficient use and re-use of at-hand physical and cultural resources that would improve well-being outcomes. In this contribution, we focus on visualising the creative approaches that communities are adopting to solar energy generation. Specifically, we are interested in tracing the flow of ideas and technologies and other resources across the Global North and Global South.

The longer-term investigation aims to develop ecological regenerative solutions to improve quality of life and contribute to a broader understanding of this under-researched and isolated region. Using solar solutions as a focal point, we explore how solutions are created with attention to local initiatives and wider nuances and implications of implementations and dissemination.

THE LARGER TROPIC OF CAPRICORN REGION

“Global South” is a concept used to describe regions 61arginalizati by shared socio-economic and political challenges. Many have historic legacies of 61arginalizat.[1] This term transcends geographical definition and includes regions in the Northern Hemisphere, 61arginaliza a shared experience of economic challenges, 61arginalization, and lack of equitable representation in global decision-making. The Global South includes diverse nations in Latin America Africa, and parts of Asia, commonly navigating issues such as poverty, limited access to resources, technologies, and systemic inequalities.

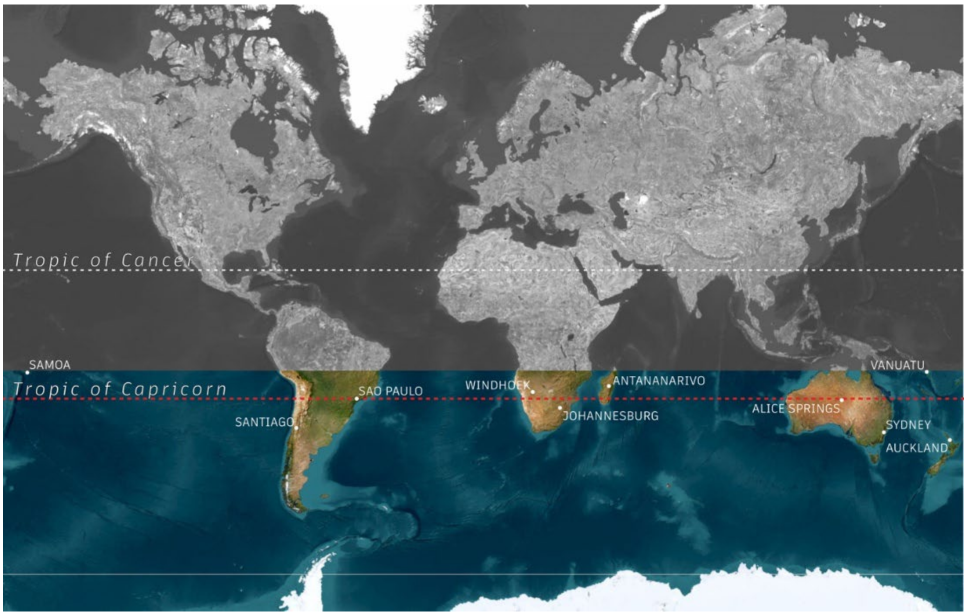

Figure 1. The Larger Tropic of Capricorn Region. The coloured area shows the area of interest; the region just north and south of the Tropic of Capricorn.

The Tropic of Capricorn (Latitude 23.4° South) marks the southern boundary of the tropics. The region north and south of the Tropic of Capricorn includes countries from both the Global North and Global South including the Pacific Islands, South America, the southern part of Africa, Australia and New Zealand (Figure 1). The communities in this larger Tropic of Capricorn region have similar geopolitical and colonial histories, typically have distributed, sparse populations, and face challenges dissimilar to countries in the Northern Hemisphere. Some of the issues and challenges facing communities in the Global South are shared by specific, marginalised communities within the Global North countries in this region.[2] Approaches such as the Fourth World movement contribute to an evolving discussion on the recognition of the contrasting lived experience of indigenous communities within so-called Global North or First World spaces.[3] In addressing solutions to some of the complex and deeply embedded issues facing these communities, applying a specific lens to these regions could reveal responses or approaches to solutions that could help empower communities as well as help to forge connections between communities. Here we are interested in how communities may be able to share similar-enough solutions by adapting local, global, traditional, indigenous, and contemporary technologies with efficient use and re-use of at-hand physical and cultural resources to better understand solutions that *may* work in these environments.

SOLUTIONS

Addressing complex and wicked problems facing communities in the larger Tropic of Capricorn region has many challenges where the type, quantity, access, and efficacy of resources to address these challenges is constrained in inconsistent and non-distributed ways. Communities may be resource-rich in some areas but not in others. Initiatives to address the needs of communities vary from centralised top-down government, Non-governmental organisations (NGOs), market-driven approaches to grassroots movements. The Sustainable Development Goals (SDGs) and similar initiatives address the need to distribute and spread the impact of solutions to improve wellbeing for all. While there has been some success in working toward the SDGs, top-down or centralised approaches that do not engage meaningfully with communities that are intended to be supported can be unsustainable and ineffective. Where solutions can build on resources in which a community is already rich there is a greater chance of dignified and meaningful development.[4] Opportunistic engagement with at-hand resources, whether they be physical materials, financial, cultural knowledge or social capital, is an essential part of both problem-framing and solution development.[5] The complexity of specific challenges in resource-constrained environments requires a deep understanding of communities and their needs, recognising that different communities have different ways of being and value systems. Problem-solving in this context involves supporting communities to live the lives they value.[6]

An example of the complexity of initiatives to improve well-being can be seen in two projects in Namibia. In the eastern regions of Namibia, one of the sparsest populated places on Earth, expansion of a central grid to provide electricity is impractical. A hybrid solar-diesel mini-grid commissioned in 2008 in Tsumkwe Village in Otjozondjupa region to supply electricity for household and commercial use attempts to improve the income-generating potential of the community.[7] Tsumkwe is known as the capital of the indigenous San people who have lived in Southern Africa for some 20,000 years. Traditionally, the San are a nomadic people. The mini-grid improved safety at night with streetlights, reduced the use of increasingly scarce biomass for heating, and improved the capacity to store food. The overall socio-economic impacts of this mini-grid project are less clear. Ongoing maintenance requirements necessitate secured financial support, supply of parts, and specialist knowledge that is not easily transferable to local workers.[8] By contrast, 300km to the south of Tsumkwe in Omaheke region, the NGO Desert Research Foundation of Namibia (DRFN) is equipping 90 San community households with small, independent solar home systems. The nomadic lifestyle of the communities is at odds with the urbanising influence of centralised or mini-grid systems and the solar home systems appear to be a more complimentary response. Local women will be trained in the basic installation and maintenance of the systems to mitigate the risk associated with maintenance and ongoing support for remote areas, and provides economic opportunity with the establishment of a women's co-operative.[9] Utilising at-hand resources in this way can create a broader, more sustained impact.

Innovation and Creativity

Innovation and creativity are essential for the transition to a low-carbon economy, one of the central values of the Sustainable Development Goals (SDGs). However solutions are driven, innovation in resource-constrained environments requires creatively and directly addressing the immediate needs of a community. Approaches to innovation, or the realisation of solutions, in these contexts are well-researched and categories documented.[10]

Innovation Strategy	Definition
Top-down	Centralised, strategic approaches that are hierarchical and linear in nature. Includes government-led policies and initiatives as well as private-sector projects. Initiatives can engage with large-scale, infrastructural goals that may benefit more than one community. Can involve technology or intellectual property transfer.[11] Effectiveness can be limited by a lack of agility and responsiveness to specific contexts and situations.
Disruptive	Innovations or technologies that significantly alter existing systems and processes. Tend to begin as offerings by smaller companies to niche markets and communities that then redefine modes of practice and norms leading to system change and the creation of new markets.
Frugal	Minimisation of waste through careful and efficient use of resources often driven by the translation of a product into a more resource-constrained area. Similar to top-down approaches, often involves dedicated, structured research and development. Frugal innovations are seen as less resource intensive or simplifications of processes that could help the diffusion of solutions to underserved communities.[12] Reverse innovation occurs where solutions developed in resource-constrained environments are adapted and introduced into developed markets.[13]
Grassroots	Socially-driven bottom-up approach to problem-solving. Community-driven, inclusive, driven by social impact. Tend to engage with systemic issues.[14]
Bricolage	Creative construction through use of at-hand resources. Typically doesn't involve formal research and development, rather creates solutions through improvisation, repurposing and flexibility.[15] Barriers or constraints may be institutional, network-based or 'perceived'.[16] Bricolage may occur in areas where inappropriate resources are abundant.
Good-Enough	Solutions that meet immediate needs and minimum acceptable requirements. Can be seen in urgent situations or rapidly changing conditions.

Table 1. Innovation Approaches

All of the approaches described in Table 1 engage with resource-constrained environments in some way. Whether it is a financial, cultural, material or other resource constraint, is important to acknowledge the resources that a community does have when addressing an issue; a community may be resource-rich in some ways.[17] Initiatives that explore grassroots or local innovation such as United Nations Development Programme Accelerator Lab and MIT Solver acknowledge the value of working with what is already at hand, nearby, or abundant in a community.

Solar Solutions

As a resource that in recent times has growing technological and financial barriers to entry, energy (in)security impacts the community and household well-being. In addition to the security of production and supply ongoing access to electricity through operational availability and pricing impacts equity and justice.[18] Pragmatic goals to deliver electricity to communities can paradoxically overlook the development of just energy systems that empower communities to "live the life they value" and enable self-determination.[19]

Electrification is a key strategy that is central to the SDGs. SDG 7 Affordable and Clean Energy targets affordable, reliable access to energy for all. Typically, conventional approaches to increasing the capacity of renewable energy resources have involved significant investment in large, centralised infrastructures thereby excluding rural, remote and economically stressed communities. Capital investment in large infrastructure thereby favours large, dense populations and centralised systems of energy generation exacerbate the isolation of marginalised communities, both physically and financially. These infrastructures are inequitable not only in terms of supply of energy but also in the influence they have on power relations, namely energy justice.[20] In recent years there has been an on-average decrease in international public financial flows into clean energy initiatives.[21]

There are also differences between Global North and Global South countries. Advanced economies focus on the transition to cleaner forms of energy production while the priority of developing economies tends toward energy security in the form of reliable affordable access to energy. As well as increasing electricity generation, alternative solutions to utilise solar power also support the resilience of energy systems. For example, supplying solar cooking, solar water heating, refrigeration and lighting.

Tropic of Capricorn communities are exposed to the impacts of non-renewable energy generation despite not benefitting from it.[22] There exists uneven participation in the global energy sector as developed economies and countries transition to low-carbon energy systems. However, the transfer to the Global South is slow.[23] Energy communities can help areas in developing countries develop low-emission economies for long-term, embedded resilience.[24]

We find alternative approaches to centralised electricity grids that include mini-grids, micro-grids and standalone Solar Home Systems (SHS). Electricity supplied by off-grid renewable energy allows for a "leapfrogging" of technologies in similar ways to cellular networks in telecommunications and more recently Starlink satellite internet.

SOLUTIONS MAPPING VS MAPPING SOLUTIONS

Solutions Mapping is a structured approach to identifying and evaluating solutions to specific problems or challenges.[25] Solutions Mapping unpacks the interconnectedness between communities, challenges faced, resources available, definitions of success and pathways to achieving that success. The Accelerator Labs is an initiative of the United Nations Development Programme.[26] The initiative is an outward-facing, agile network that connects grassroots, community problem-solvers and innovators who are making local decisions and taking local action to address sustainable development challenges. There exists more than 90 ‘labs’ covering 115 countries primarily in the Global South. Each lab has three key members; Head of Solutions Mapping, Head of Experimentation, and Head of Exploration. The Accelerator Labs initiative emphasises local communities as a source of change and encourages the cross-pollination and sharing of grassroots solutions from across the world.

Visualisation of these actors and relationships is an impactful way to understand underlying structures that may support or constrain efforts to develop meaningful solutions. As a method of visualisation, and in line with our interest in relationships within, across, to and beyond the larger Tropic of Capricorn region the geographic mapping of solutions can enhance understanding of how innovative or creative solutions may interconnect, or indeed, how future connections may be made. These relationships or emerging patterns form narratives for deeper understanding and communication amongst communities.

Geographic mapping is a form of visualisation that explores spatial connections between actors. In recent years access to digital tools for the collection and communication of geographic information has led to greater community-led participatory approaches to mapping that enable new narratives to evolve.[27]

METHOD

There are a plethora of actors from grassroots individuals to top-down public development funds engaged with solar solutions. We collected data from case studies across the larger Tropic of Capricorn region via web searches and academic databases. Information publicly available and communicated gives insight into the priorities or values of each of the projects. We trawled these web pages for information on innovation strategy, relationships, and funding sources. We then identified relevant SDG goals, geolocated all actors, categorised them (see Table 2) and proceeded to visualise these in an open web map (https://nearbyhere.github.io/), see Figures 2 and 3.

Category	Terms
Innovation Strategy	Top-down
	Disruptive
	Frugal
	Reverse
	Grassroots
	Bricolage
Relationships	Investor/Funder
	Stakeholders
	Collaborator
	Technology Transfer
	Community
	Supplier
Organisational Structures and Funding Sources	Private (Domestic)
	Private (Foreign), Corporate or venture capital funding
	Public (domestic), Grants and scholarships, programmes and initiatives from central or local government.
	Public (Foreign), Foreign grants, scholarships.
	Non-Governmental Organisation, Non-Profit Organisation, Social Enterprise

Table 2. Solar Solution Case Study Categories and Definitions

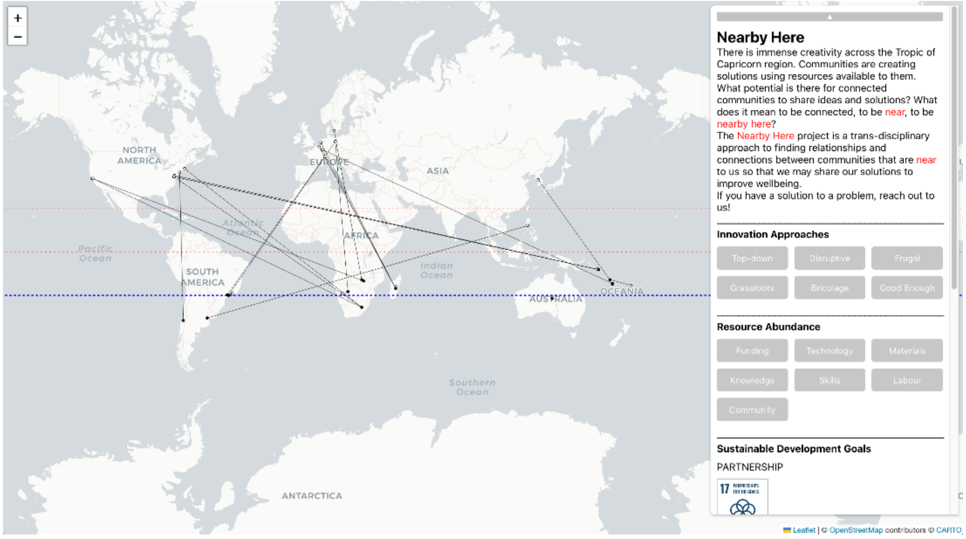

Figure 2. The Nearby Here interactive web map (https://nearbyhere.github.io/). Connections between actors in projects are visualised. Flows between north and south dominate the visualisation over connections across the larger of Tropic of Capricorn region.

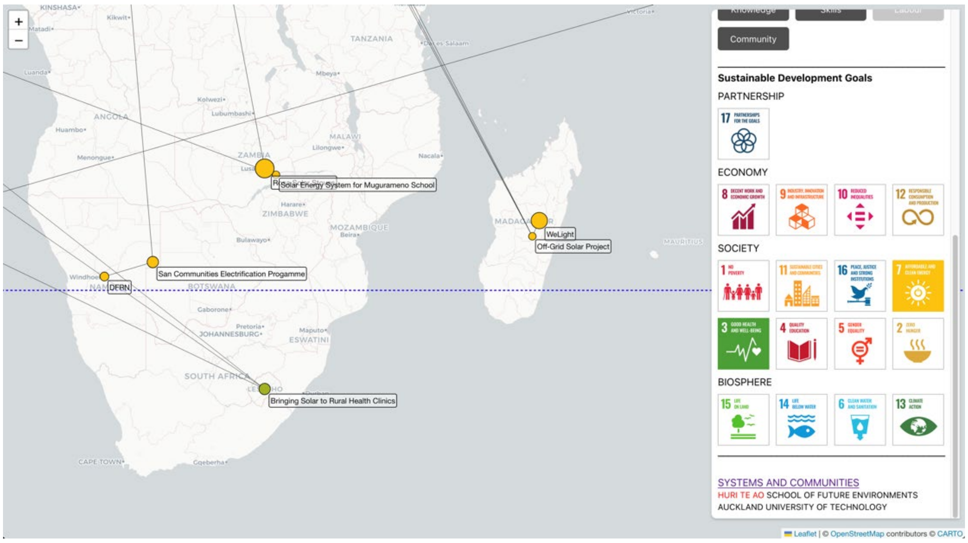

Figure 3a. Each of the case studies and associated organisations and partners are geolocated and displayed within the interactive map.

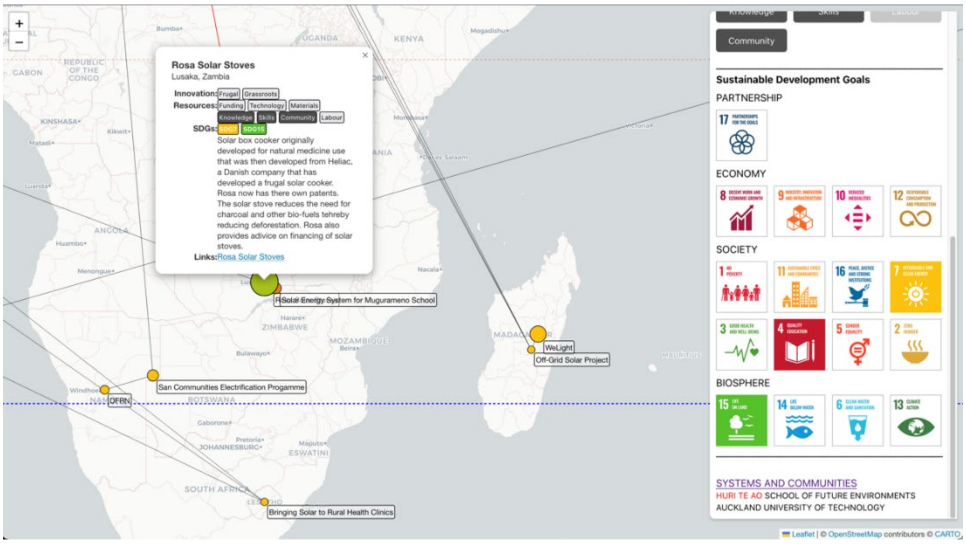

Figure 3b. The case studies are categorised using the standardised tags and a short description of the project with links to source information provided. Relationships and patterns can be discovered by selecting tags.

FINDINGS AND DISCUSSION

In reviewing and mapping these cases here we find a set of themes and questions that might drive further research and investigation.

The Geographical Mapping of Solutions

Solutions mapping reveals underlying structures, ways of knowing, and relationships that drive creativity, realisation, capacity-building, and empowerment within communities. The geographical mapping of activities and relationships provides a complementary lens to solutions mapping approaches because it can uncover patterns and emerging trends in the structures and systems that may support or hinder the development of solutions in the larger Tropic of Capricorn region. Many of the solutions we have explored utilise resources from other places but simultaneously have a specificity that unlocks potential within communities. In our investigation, geographic mapping allows us to begin to understand patterns in this dynamic and then discuss opportunities for nearby-here utilisation of solutions. Understanding all of the (economic, material, cultural, social) resources available in any given situation is essential for beginning conversations about the transfer of solutions across the Larger Tropic of Capricorn region.

Innovation and Creativity in Solar Solutions

Geographic mapping creates an opportunity to holistically view the relationships and interconnections between the various approaches to create solutions in these vulnerable communities. Top-down, centralised approaches are established strategies that engage with trans-scalar problems. These may be outside of the influence of the communities affected the most by the problems or issues being addressed. We see a strong relationship between Global North and Global South countries in mapping these projects. Primarily this takes the form of funding through grants and investment, as well as through technology transfer. Connections within and across the larger Tropic of Capricorn region tend to be restricted within political boundaries.

We note that grassroots and bottom-up approaches tend to engage with a broader range of SDGs where solutions have a number of benefits above and beyond the supply of energy. Examples of this include the establishment of economic activity or environmental improvement. The ability of these localised solutions to engage with multiple benefits and outcomes aids deeper systemic change.

Resource-rich and Resource-poor

Resources, whether financial, cultural, material or otherwise are abundant to various degrees across all communities and solutions that utilise what is at-hand tend to have broader impacts that can be overlooked when using the terms Global North and Global South. A more sophisticated discussion and understanding of contemporary relationships between Global North and Global South, as well as expansion on Fourth World thinking as a useful applicable concept, is required to more readily fit the kinds of concerns raised in this investigation and more generally where mixed economies are the predominant norms. A nearby-here approach to solution finding requires a more nuanced discussion around the relationships and connections between actors as well as an acknowledgement and appreciation of less tangible outcomes to help us respond better to what is happening “here” and “now”.

Diffusion and Spread of Nearby-Here Solutions

The central theme of this research is to explore the potential for the transfer and spread of solutions amongst communities. Understanding the overlap or connection between approaches nearby-here helps us to see that communities across the larger Tropic of Capricorn regions may be able to support one another. Conventional differentiations between Global North and Global South, and resource-rich and resource-constrained do not capture or support the opportunities that exist across the communities that inhabit this part of planet Earth.

In our most immediate surroundings, “here” and “now”, recent flooding events in Tāmaki Makaurau Auckland have revealed a stark lack of resilience and agility to creatively respond to quickly changing circumstances. We find a reliance on more contemporary technology solutions is the ‘go-to’ response. This approach conflicts with working alongside the previously established and workable indigenous, preventive methods that work with the land and conditions—applying traditional knowledges—and is a recurrent theme. Consequently, a more dynamic, agile approach that recognises and engages with nearby-here resources and solutions can better support a transformation towards more resilient, livable cities and supportive environments.

NOTES

[1] Fry, “Design for/by ‘The Global South’”; Dados and Connell, “The Global South.”
[2] Manuel and Posluns, “The Fourth World.”
[3] Whetstone and Yilmaz, “Recreating the Third World Project: Possibilities through the Fourth World.”
[4] Gupta, “Tapping the Entrepreneurial Potential of Grassroots Innovation.”
[5] Gupta, “Innovations for the Poor by the Poor.”
[6] Mang-Benza et al., “Making Energy Justice Work for Women in Rural Sub-Saharan Africa: A Qualitative Diagnostic from Benin, Senegal, and Togo.”
[7] Klintenberg, Wallin, and Azimoh, “Successful Technology Transfer: What Does It Take?”
[8] Wamukonya and Davis, “Socio-Economic Impacts of Rural Electrification in Namibia: Comparisons between Grid, Solar and Unelectrified Households.”
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[12] De Marchi et al., “Frugal Innovation and Sustainability Outcomes: Findings from a Systematic Literature Review”; Busch, “Frugal Innovation in Energy Transitions: Insights from Solar Energy Cases in Brazil”; Hossain, “Frugal Innovation: Unveiling the Uncomfortable Reality.”
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[14] Roysen et al., “Rethinking the Diffusion of Grassroots Innovations: An Embedding Framework.”
[15] Mateus and Sarkar, “Bricolage- A Systematic Review, Conceptualization, and Research Agenda.”
[16] Ciambotti et al., “Opportunity Recognition and Exploitation in Resource-Scarce Contexts: The Role of Relational Capital and Bricolage in African Social Enterprise”; Papazu, “Entrepreneurial Resource Construction Through Collective Bricolage on Denmark’s Renewable Energy Island: An Ethnographic Study.”
[17] Gupta, “Innovations for the Poor by the Poor”; Gupta, “Tapping the Entrepreneurial Potential of Grassroots Innovation.”
[18] Jenkins et al., “Energy Justice: A Conceptual Review.”
[19] Mang-Benza et al., “Making Energy Justice Work for Women in Rural Sub-Saharan Africa: A Qualitative Diagnostic from Benin, Senegal, and Togo”; Ambole et al., “A Review of Energy Communities in Sub-Saharan Africa as a Transition Pathway to Energy Democracy.”
[20] Mang-Benza et al., “Making Energy Justice Work for Women in Rural Sub-Saharan Africa: A Qualitative Diagnostic from Benin, Senegal, and Togo.”
[21] “UN SDG Goal 7 Progress and Info.”
[22] Mang-Benza et al., “Making Energy Justice Work for Women in Rural Sub-Saharan Africa: A Qualitative Diagnostic from Benin, Senegal, and Togo.”
[23] Weko and Goldthau, “Bridging the Low-Carbon Technology Gap? Assessing Energy Initiatives for the Global South.”
[24] Ambole et al., “A Review of Energy Communities in Sub-Saharan Africa as a Transition Pathway to Energy Democracy.”
[25] “SOLUTIONS MAPPING | United Nations Development Programme.”
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[27] Lan et al., “From Data to Narratives: Scrutinising the Spatial Dimensions of Social and Cultural Phenomena Through Lenses of Interactive Web Mapping”; Sullivan-Wiley, Short Gianotti, and Casellas Connors, “Mapping Vulnerability: Opportunities and Limitations of Participatory Community Mapping”; Backman and Lööf, “The Geography of Innovation and Entrepreneurship.”

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URBAN TRANSFORMATION VIA SUSTAINABLE BUILDING STOCK AND TRANSPORTATION

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INTRODUCTION

The ongoing accumulation of greenhouse gases (GHGs) is leading to a gradual rise in global average temperatures. Among these gases, carbon dioxide (CO2) plays a pivotal role, with its increasing levels contributing to a global temperature rise of approximately 1.4°C.[1] Projections from the International Energy Outlook 2023 indicate that CO2 emissions linked to energy consumption are expected to continue their upward trend through 2050.[2] Despite the implementation of various international agreements aimed at mitigating global warming, the issue persists, exacerbated by the continued rise in GHG concentrations.[3] A large share of these emissions stems from human activities, particularly in sectors such as buildings and transportation, both of which are heavily reliant on energy consumption. In 2020, the building sector alone was responsible for roughly 35% of the world's energy use, with residential buildings contributing the most at 22%.[4] Meanwhile, road transport accounted for a significant portion of transportation energy consumption, making up 55% in OECD countries and about 45% in non-OECD countries.[5]

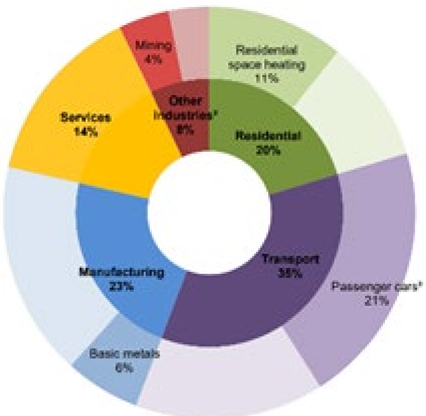

Figure 1. Global sectoral energy use distribution.

In Pakistan, residential buildings are responsible for about 45% of the country's total energy consumption, while road transport contributes around 31.4%.[6] This significant energy use in both sectors has led to a noticeable increase in CO2 emissions. Electricity and natural gas are the primary

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energy sources for buildings, whereas road transport predominantly relies on gasoline and diesel. While there are studies that examine energy consumption and CO2 emissions in these sectors, they often address them separately. This separation is particularly evident in Pakistan, where energy use and GHG emissions from buildings and road transport are typically analyzed independently.[7] However, to effectively combat climate change, it is essential to understand the connection between these sectors, especially in the context of land use and transportation. Buildings, for instance, consume energy through operations that rely on electricity and natural gas. Additionally, the energy used for travel to and from buildings, known as transport energy use, also plays a significant role. The following figures illustrate the domestic and transport energy consumption, along with GHG emissions forecasts in Pakistan.

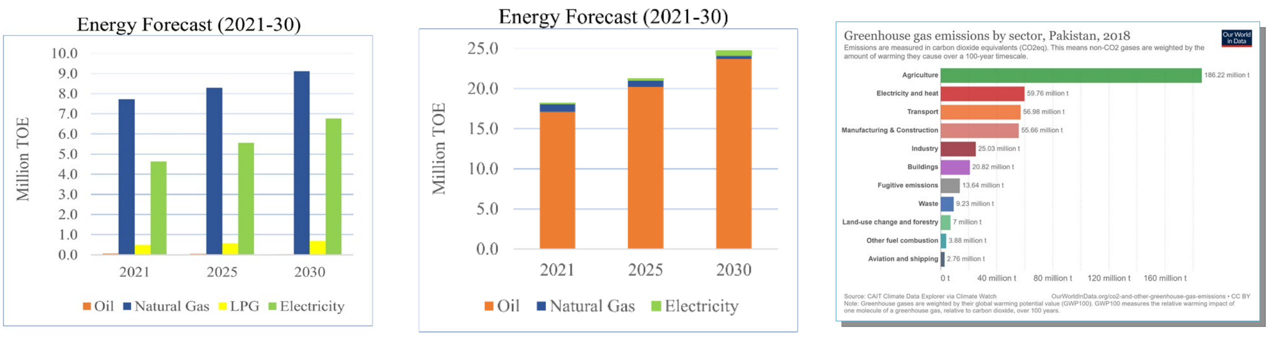

Figure 2. Domestic and transport energy use & CO2 emissions.

In Pakistan, rapid urbanization and population growth have intensified challenges related to housing, transportation, energy use, and CO2 emissions, particularly in Lahore. The city's urban landscape includes both high-density and low-density areas to accommodate its expanding population. To address these issues, the Bus Rapid Transit (BRT) system was introduced in 2012 to reduce reliance on private vehicles by promoting public transport, aiming to improve energy efficiency and support environmental sustainability.[8] However, despite the BRT's implementation, progress in reducing CO2 emissions has been limited.

In Pakistan, research on carbon has predominantly focused on the transportation sector, with comparatively little attention given to emissions from buildings.[9] This study explores carbon emissions in Lahore, the nation's second-largest city and a mass transit leader. It examines emissions from operational energy use (electricity and natural gas) in residential buildings along Lahore's BRT corridor and transport energy linked to these buildings. Utility bills provide energy consumption data, while transport emissions are calculated using average travel distance, transport modes, and energy efficiency. Multinomial regression analysis in SPSS identifies causal relationships between surveyed variables and energy consumption.

CASE STUDY: LAHORE, PAKISTAN

Lahore, the second-largest city in Pakistan, is home to over 11 million people. This rapidly growing metropolis displays significant diversity across its nine towns, tehsils, and more than two hundred Union Councils.[10] Ranked as the 122nd largest city in the world by GDP, Lahore boasts an impressive average growth rate of nearly 6%.[11] The city's infrastructure includes a complex transportation network integrated with densely built structures. The Bus Rapid Transit (BRT) system, which runs along a 27-kilometer corridor, stands as Lahore's largest transit initiative, serving areas with a variety of building types.[12]

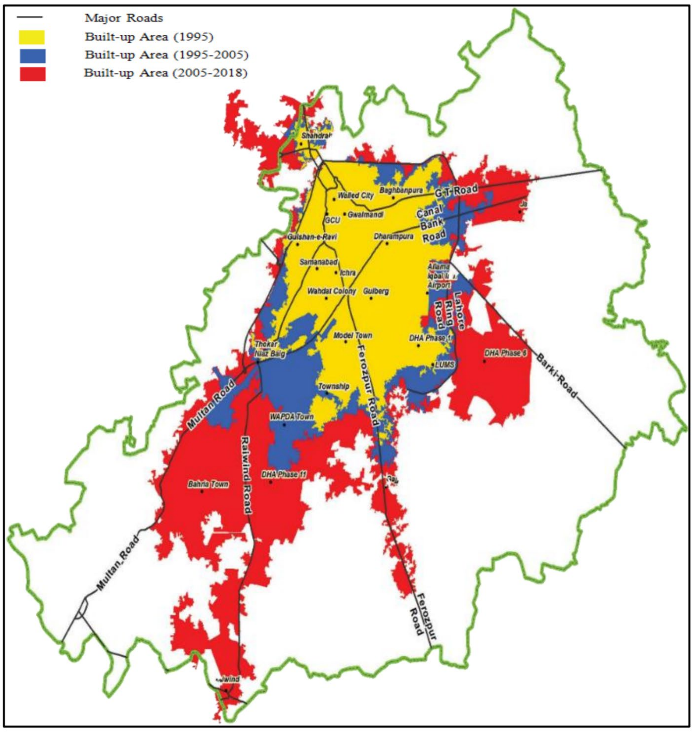

Figure 3. Spatial growth of Lahore.

Year	Population	Growth Rate (%)	Growth
1950	835,769	0.00%	
1955	1,021,679	4.10%	185,910
1960	1,264,277	4.35%	242,598
1965	1,574,981	4.49%	310,704
1970	1,963,951	4.51%	388,970
1975	2,398,576	4.08%	434,625
1980	2,881,596	3.74%	483,020
1985	3,387,873	3.29%	506,277
1990	3,970,161	3.22%	582,288
1995	4,652,529	3.22%	682,368
2000	5,576,372	3.69%	923,843
2005	6,856,969	4.22%	1,280,597
2010	8,432,132	4.22%	1,575,163
2015	10,369,137	4.22%	1,937,005
2019	12,188,196	4.12%	1,819,059
2020	12,642,423	3.73%	454,227
2025	14,825,828	3.24%	2,183,405
2030	16,883,085	2.63%	2,057,257
2035	19,116,605	2.52%	2,233,520

Table 1. Population growth of Lahore, World Population Review.

This study examines the building stock along Lahore's BRT corridor near Ichhra, Kalma Chowk, and Azadi Chowk stations, assessing buildings and transport systems for sustainable practices. Introduced in 2013, Lahore's BRT was Pakistan's first mass transit project aimed at environmental sustainability (Figure 4). However, progress toward sustainability in transport and adjacent buildings remains limited before and after its implementation.

Land development along Lahore's BRT corridor features a mix of old and new buildings, planned developments, unplanned neighborhoods, and varying population densities. The route passes through established urban areas with some buildings in disrepair and underutilized land. Revitalization and redevelopment are needed to improve energy efficiency and reduce greenhouse gas emissions.

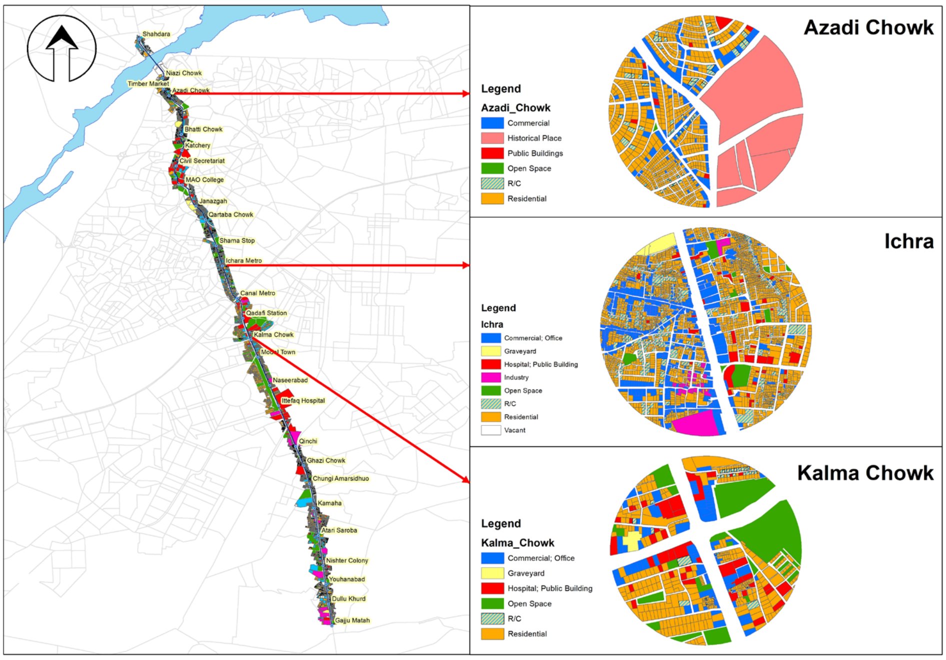

Figure 4. BRT and the chosen station points.

STUDY OBJECTIVES

Following are the key research objectives:

- To quantify building stock operational and transport energy use for residential buildings in KWH
- To quantify the resulting CO2 emissions in MTCO2
- To examine the impact of various survey variables on energy consumption
- To investigate the interrelationship between a building's operational energy use and its transport energy use.
- To propose strategies and/or recommendations for reducing CO2 emissions by integrating efforts to reduce overall building energy consumption

STUDY DESIGN & METHODOLOGY

This research used a questionnaire-based cross-sectional study with a random sample of 120 residential buildings within a 500-meter radius of three station points. Conducted during peak summer, the survey assessed monthly energy consumption from buildings and transport. The questionnaire covered socio-economic factors, building characteristics, and transport/trip details. Data on operational energy use (kWh) for buildings came from utility bills, while transport energy use (kWh) was calculated using a formula in Eq. 1. Carbon dioxide emissions are quantified using the IPCC methodology and using the following equations in table 2:[13]

Type	Equation
Buildings operational energy use	$CO2_{electricity}$ = Consumption (KWH) x Emission Factor (EF) $CO2_{natural\ gas}$ = Consumption (KWH) x Emission Factor (EF)
Buildings transport energy use	$CO2_{petrol}$ = Consumption (KWH) x Emission Factor (EF) $CO2_{diesel}$ = Consumption (KWH) x Emission Factor (EF)

Consumption Category		Emission factor		
		kg CO_2	kg CH_4	kg N_2O
Electricity (kwh)		0.615374995	0.00001798722	0.00000316016
Natural gas (kwh)		0.05444	0.00103	0.00010
Mobile combustion (transport) (gallon)	**Petrol**	8.78	0.3516667	0.0318667
	Diesel	10.21	0.57	0.26
Source: Brander et al., 2011; IEA, 2010a; IEA, 2011a, 2011b; IPCC, 2006; EPA, 2016; DEFERA, 2011b; EPA, 2010)				

Table 2. CO2 emissions equations and Pakistan specific emission factors.

Transport energy use (KWH): distance travelled (km) x no. of trips x fuel efficiency for a vehicle (km/units of fuel) ….eq1

Three different categories of variables were taken into account i.e. socio-economic, building characteristics and transport characteristics. Following table lists down the different variables considered within these categories as independent variables and our dependent variable.

A total of 20 independent variables were assessed.

Dependent Variable		
Total operational energy use of building = Energy use from electricity + Energy use from natural gas in KWH Total transport energy use of building = Energy used from the fuel x distance travelled in KWH		
Independent Variables		
Socio-economic	**Building Characteristics**	**Transport characteristics**
1. Household size 2. Monthly income 3. Occupation	4. Area in sq meters 5. No. of storeys 6. Year of construction 7. No. of rooms 8. No. of windows 9. Window material 10. Window insulation 11. Building material outside 12. Building material inside 13. Building insulation 14. No. of electrical appliances 15. No. of heating appliances	16. Vehicle ownership 17. Preferred mode of use 18. Use of BRT 19. Ave. distance travelled per day 20. Frequency of travel

Table 3. Dependent & independent variables.

Statistical Package for Social Sciences (SPSS) was used to analyze the data. Descriptive statistics was generated for all the considered variables including the dependent variables to assess the frequencies and percentages within the dataset. Multinomial regression was done to study the interrelationship between the categories of these variables and to see the effect.

ANALYSIS & RESULTS

The analysis is divided into three broad categories. The first one comprises of the descriptive analysis results that gives an overview of the type of dataset examined for this research. The second involves the calculation of building stock operational and transport and energy use and associated CO2 emissions using the IPCC methodology. The third category is based on the multinomial regression where probable relations and effects of different variables is examined. Out of the 20 variables, 8 variables came out to be significant and the results for which are explained within the analysis.

Building Operational & Transport Energy Use

This study analyzes energy use and carbon emissions from building operations and transportation using the IPCC methodology (Table 2). Average energy consumption per housing unit in kilowatt-hours (kWh) and corresponding metric tons of CO2 (MTCO2) emissions were calculated for electricity, natural gas, and transport. Results show average electricity use of 942.667 kWh, emitting 0.586 MTCO2; natural gas use of 966.523 kWh, emitting 0.179 MTCO2; and transport energy use of 1001.00 kWh, emitting 2.312 MTCO2. These findings emphasize transport's higher carbon footprint, highlighting the need for targeted emission reduction strategies.

Building Operational & Transport Energy Use		
Average	**KWH**	**MTCO2**
Electricity	942.667	0.586
NG	966.523	0.179
Transport	1001.00	2.312

Table 4. Energy use (KWH) & CO2 emissions (MTCO2).

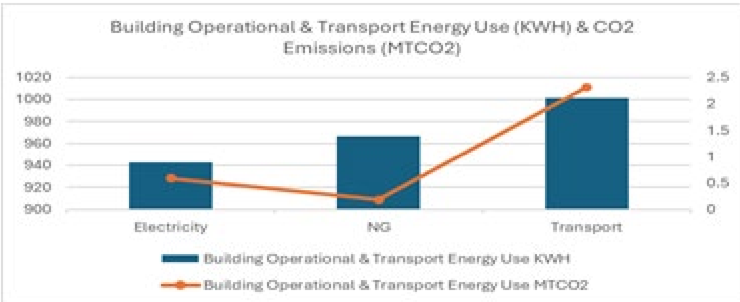

Figure 5. Building operational & transport energy use & CO2 emissions

Electricity and Natural Gas both have substantial energy consumption levels, but their CO2 emissions are relatively modest compared to transport. This suggests that improvements in the efficiency of electrical systems and the adoption of cleaner energy sources could further reduce emissions. With the highest energy use and CO2 emissions, transport represents a significant challenge for sustainability. The disproportionate emissions from transport emphasize the need for strategies such as enhancing public transport infrastructure, promoting electric vehicles, and encouraging non-motorized transport options.

Descriptives

The following table gives an overview of different variable in the dataset and their corresponding percentages:

Socio-Demographic	
Variable	**%**
HH Size	
Nuclie	10.7
Single	64.8
Double	16.3
Composite	8.2
Monthly Income	
<20,000	22
20000-60000	53
>60	25
Occupation	
Govt. employee	36.1
Pvt. Employee	9.9
Businessman	25.1
Unemployed	5
Student	11.2
Retired	7.4
Other	5.3

Building Characteristics	
Variable	**%**
Area (sq. m)	
<127	13.15
127-253	28.7
253-380	34.5
381-506	14.7
>505	8.9
No. of Storeys	
Single	16.8
Double	52.4
Triple	30.6
Age of Building	
Before 2010	32.9
2010-2012	26.2
2013-2015	39.9
2016-2018	1.6
2019-2021	0
No. of Rooms	
<3	2.5
4	15.1
5	22.5
6	35.4
7	16.7
>7	7.8
Building Material Outside	
Cement Concrete	37.1
Cement Brick	29.9
Only Brick	22.3
Only Concrete	3.3
Other	7.4
Building Material Inside	
Cement Concrete	25.6
Cement Brick	19.9
Drywall Plaster	23.4
Only Brick	29
Other	2.1
Building Insulation	
Yes	8.1
No	91.9
Window Insulation	
Yes	9.8
No	90.2
Window Material	
Aluminium single glazed	48.9
Aluminium double glazed	3.8
Wood Clad	47.3
uPVC	0
No. of heating appliances	
5-10	71.8
11-20	27.2
>20	1
No. of electrical appliances	
5-10	16.3
11-20	51.1
>20	32.6

Transport Characteristics	
Variable	**%**
Vehicle Ownership	
None	11.5
Car	27.2
Motorbike	43.3
Bicycle	8
--Other	10
Use of Metrobus	
Yes	20.5
No	36.1
Sometimes	41.8
Mode Choice	
Owned Vehicle	49.8
Metrobus	31
Other PT	11.1
Foot	8.1
Distance travelled/day	
<5 km	1.3
5-10 km	19
11-20 km	58
21-30 km	15.7
>30 km	6
Frequency of Travel	
Everyday	20.5
5 days a week	17.2
6 days a week	28.4
Only weekends	23.8
Few times in a month	8.5
Mode Choice Reason	
Convenient	23
Comfortable	8.2
Cost effective	12.3
High speed	18
Accessible	11.5
All of the above	23
Other	2.5

Building Energy Consumption	
Variable	**%**
Monthly Electricity Consumption (kwh	
<300	0.8
300-500	18.9
501-1000	45.9
1001-1500	27
1501-2000	4.9
>2000	2.5
Monthly Gas Consumption (kwh)	
100-300	8
301-500	35.8
501-700	21
701-900	11
901-1100	15
1101-1300	4
1301-1500	4
1501-1700	0.2
>1700	1
Energy Consump. (gallons to kwh eqv.)	
>300	17.5
300-500	12.3
501-1000	19
1001-1500	26
1501-2000	9.4
2001-2500	11
>2500	4.8

Table 5. Results of descriptives.

Multinomial Regression

This study uses multinomial regression to analyze and predict categorical outcomes, effectively identifying factors influencing preferences across categories. Variables such as household size, income, storeys, appliances, insulation quality, building materials, transportation mode, and travel distance were examined for their impact on product choices. The method estimates the likelihood of selecting each category, highlighting the predictors' relative influence. Table 6 presents parameter estimates for operational and transport energy use categories, detailed by household size, income, storeys, insulation, and building materials.

Operational Energy Use

The baseline intercept values represent the log-odds of a household being in each energy use category (<300, 300-500, 501-1000, 1001-1500, 1501-2000, >2000 kWh) when predictors are at reference levels. Nuclear families are more likely to fall into the 300-500 and 1001-1500 kWh categories, with significant positive coefficients ($\beta = 1.72$ and $\beta = 1.92$). Single households show strong positive effects in these ranges ($\beta = 2.08$ and $\beta = 2.49$). In contrast, double households are less likely to be in higher energy categories compared to composite households. Households earning below PKR 20,000 are less likely to fall into higher energy categories, while those earning PKR 20,000-60,000 have a greater likelihood, indicating a positive income-energy use correlation. Single-storey buildings are generally less likely to be in higher energy categories, while double-storey buildings show mixed effects. Households with 5-10 and 11-20 appliances are more likely to fall into 300-500 and 1001-1500 kWh categories, while 5-10 heating appliances lower the likelihood of higher energy use, suggesting efficient heating reduces consumption. Insulated buildings consistently show lower probabilities of high energy use, highlighting the importance of insulation. Similarly, window insulation significantly reduces energy consumption. Concrete buildings are more likely to fall into higher energy categories compared to those made of cement concrete or brick, indicating lower energy efficiency.

Transport Energy Use

The baseline intercept values indicating the log-odds for transport energy categories, similar to operational energy use. Owning a vehicle significantly decreases the likelihood of being in higher energy categories compared to walking, which serves as the reference category. Additionally, using Bus Rapid Transit (BRT) also notably reduces the likelihood of falling into higher energy categories, highlighting the greater energy efficiency of public transport. Shorter travel distances (<5 km) are associated with a higher likelihood of being in higher energy categories, likely due to the energy consumed in frequent short trips. Conversely, longer travel distances are linked to a lower likelihood of higher energy categories, suggesting that travel over longer distances tends to be more energy-efficient.

Model fit & significance

The Likelihood Ratio Tests reveal that the full model provides a significantly better fit compared to the intercept-only model, with a Chi-square value of 1705.80 ($p < 0.001$). The model's explanatory power is further supported by Cox and Snell, Nagelkerke, and McFadden's pseudo-R-squared values, which indicate a moderate fit (Cox and Snell = 0.590, Nagelkerke = 0.600, McFadden = 0.214).

Parameter Estimates

Operational Energy Use (KWH)	<300	300-500	501-1000	1001-1500	1501-2000	>2000
	β	β	β	β	β	β
Intercept	2.69	-0.22	2.09	2.69	4.61	1.65
Household size						
Nuclie	-0.11	1.72***	0.38	1.92***	-0.21	-1.05***
Single	0.82*	2.08***	1.28**	2.49***	0.63	0.16
Double	0.00	-0.74	-0.23	-0.43	-0.95**	-0.30
Composite	0a	0a	0a	0a	0a	0a
Monthly income (PKR)						
<20,000	1.92***	-2.82***	-1.91***	-4.31***	-2.89***	-1.01*
20,000-60,000	2.98***	1.04***	1.48***	0.31	1.99***	1.83***
>60,000	0a	0a	0a	0a	0a	0a
No. of storeys						
Single	0.00	-0.73	-0.21	-0.22	-0.91**	-0.30
Double	0.00	0.71*	0.02	-0.10	-0.19	0.13
Triple	0a	0a	0a	0a	0a	0a
No. of electrical appliances						
5-10	0.43	0.76**	0.76*	0.36	0.32	0.58*
11-20	-0.12	1.62***	0.38	2.72***	2.81	-1.95***
>20	0a	0a	0a	0a	0a	0a
No. of heating appliances						
5-10	-0.79**	-1.42***	-1.44***	-1.82***	-1.63***	-1.43***
11-20	0.47	-0.46	0.31	0.18	0.16	0.81**
>20	0a	0a	0a	0a	0a	0a
Building insulation						
Yes	-1.16***	-2.24***	-1.21***	-1.35***	-1.28***	-0.85**
No	0a	0a	0a	0a	0a	0a
Window insulation						
Yes	-1.57***	0.59	-1.44***	-0.06	-2.33***	-1.54***
No	0a	0a	0a	0a	0a	0a
Building material outside						
Cement concrete	-0.78**	-2.42***	-1.42***	-1.62***	-1.83***	-1.43***
Cement brick	0.47	-0.46	0.31	0.18	0.16	0.81**
Only concrete	1.26***	2.42***	1.31***	1.54***	1.65***	1.62**
Only brick	0a	0a	0a	0a	0a	0a
Building material inside						
Cement concrete	-0.78**	-2.42***	-1.42***	-1.62***	-1.83***	-1.43***
Cement brick	0.47	-0.46	0.31	0.18	0.16	0.81**

Only concrete	1.26***	2.42***	1.31***	1.54***	1.65***	1.62**
Only brick	0a	0a	0a	0a	0a	0a
	Full model	Intercept only	Likelihood Ratio Tests			
-2 log likelihood	4179.59	5885.39	Chi-square	Df	Sig.	
Cox and Snell	0.590		1705.80	126	0.00	
Nagelkerke	0.600					
McFadden	0.214					
a. reference category *** p-value<0.01 ** p-value<0.05 * p-value<0.10						
Transport Energy Use (KWH)	**<300**	**300-500**	**501-1000**	**1001-1500**	**1501-2000**	**>2000**
	β	**β**	**β**	**β**	**β**	**β**
Intercept	2.71	1.22	2.11	2.59	4.23	2.64
Mode choice						
Owned vehicle	-2.26***	-1.68**	-2.36***	-2.54***	-2.75***	-2.52***
BRT	-2.13***	-1.79**	-2.64***	-2.13***	-2.88***	-3.74***
Walk	0a	0a	0a	0a	0a	0a
Distance travelled (km)						
<5	1.11**	1.65**	1.70***	0.19	1.88***	2.47***
5-15	-2.13***	-1.79**	-2.64***	-2.13***	-2.88***	-3.74***
16-25	-2.26***	-1.68**	-2.36***	-2.54***	-2.75***	-2.52***
>25	0a	0a	0a	0a	0a	0a
	Full model	Intercept only	Likelihood Ratio Tests			
-2 log likelihood	4179.59	5885.39	Chi-square	Df	Sig.	
Cox and Snell	0.590		1705.80	126	0.00	
Nagelkerke	0.600					
McFadden	0.214					
a. reference category *** p-value<0.01 ** p-value<0.05 * p-value<0.10						

Table 6. Results of multinomial regression.

DISCUSSION & FINDINGS

The discussion and findings of our study highlight the critical need for sustainable urban development in Lahore, particularly in the context of energy consumption and CO2 emissions from residential buildings and transportation. The city's rapid urbanization has significantly increased energy demand and associated emissions, exacerbating environmental pollution and undermining livability. The data showed that residential buildings along the Bus Rapid Transit (BRT) corridor are major contributors to energy use, with substantial emissions resulting from both operational energy consumption and transportation activities. By applying the IPCC Tier 1 methodology, a comprehensive database linking energy use and emissions with specific building and transport characteristics was established. The findings underscore the importance of targeting transport emissions to achieve substantial reductions in overall CO2 emissions. While electricity is a significant component of energy use, its CO2 emissions are relatively lower compared to transport. The average natural gas consumption is slightly higher than electricity, but it results in lower CO2 emissions which reflects the lower carbon intensity of natural gas compared to electricity and transport. Policies aimed at improving building energy efficiency and transitioning to cleaner energy sources are also crucial for sustainable urban development. By addressing these areas, policymakers can make significant steps in reducing the environmental impact and enhancing the livability of urban areas like Lahore. The findings of the multinomial analysis reveals that socio-economic factors, household characteristics, and building attributes significantly influence both operational and transport energy use. Key findings include the positive correlation between household income and energy use, the importance of building and window insulation in reducing energy consumption, and the efficiency of public transportation modes. These insights are critical for policymakers and urban planners aiming to enhance energy efficiency and reduce CO2 emissions in urban areas like Lahore. Our findings highlight the urgency of implementing strengthened energy efficiency standards, promoting renewable energy, integrated urban planning and infrastructure and building energy efficiency. These measures are crucial for reducing the city's carbon footprint and improving air quality. Therefore, the study provides valuable insights for policymakers, architects, and urban planners, offering practical strategies to guide Lahore towards a more sustainable and low-carbon future. These findings also serve as a useful reference for other cities in Pakistan and Southeast Asia facing similar challenges of urban growth and environmental sustainability.

POLICY & RECOMMENDATIONS

Based on the findings, the following policy recommendations are proposed to promote sustainable urban development, enhance energy efficiency, and reduce CO2 emissions in Lahore:

1. Prioritize sustainable development through zoning regulations that encourage mixed-use developments, reduce urban sprawl, and minimize transportation distances and energy use.
2. Enforce stringent energy codes and standards to promote efficient building designs and incentivize retrofitting and energy management systems to lower operational energy use.
3. Provide incentives and subsidies for adopting renewable energy sources like solar and wind.
4. Encourage electric vehicles, shift from private cars to BRT, and develop cycling lanes and pedestrian pathways to lower transport emissions.
5. Launch campaigns promoting sustainable practices, energy conservation, and the benefits of public transport.
6. Continue data collection to develop evidence-based policies targeting specific energy use patterns and emission sources.
7. Use performance metrics to track sustainability progress and adjust policies to meet targets effectively.

These recommendations aim to mitigate urban growth's environmental impact, enhance Lahore’s infrastructure resilience, and improve residents' quality of life. By adopting these strategies, Lahore can reduce energy consumption and emissions, serving as a model for cities in Pakistan and Southeast Asia.

CONCLUSION

In conclusion, the study emphasizes the need for sustainable urban development in Lahore, focusing on energy consumption and CO2 emissions from residential buildings and transportation. Rapid urbanization has increased energy demands, worsening emissions and environmental pollution, which lower the city's livability. Findings reveal that areas along the Bus Rapid Transit (BRT) corridor significantly contribute to this issue, with emissions from both building operations and transportation. To tackle these challenges, the study recommends enhancing building energy efficiency, promoting renewable energy, and developing green transportation infrastructure. Integrated urban planning prioritizing sustainability is key to reducing the city's carbon footprint. Public awareness campaigns and data-driven policies are essential for achieving long-term environmental goals. By adopting these strategies, Lahore can reduce energy use and emissions, improving air quality and overall sustainability. These recommendations not only provide a roadmap for Lahore's development but also serve as a model for other cities in Pakistan and Southeast Asia facing similar challenges.

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EU CITY CALCULATOR: ENHANCING CLIMATE ACTION IN EUROPEAN CITIES THROUGH CO-CREATION AND TRANSITION PATHWAYS IN A MODELLING TOOL

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INTRODUCTION

Cities are pivotal in combating climate change and promoting sustainable development.[1] Urban areas are responsible for 70% of global greenhouse gas (GHG) emissions and 78% of energy consumption, yet they also serve as fertile ground for innovative actors and modern concepts to operate and proliferate,[2] positioning them at the forefront of the transition to a low-carbon future. Local governments are essential in implementing policies to meet national climate goals, often showing high ambition to cut emissions. However, many cities face challenges in developing and implementing climate action plans due to financial constraints, increasing complexity and interconnectedness of the urban fabric, lack of capacities, limited sustainability networks, in addition to a variety of political challenges.[3] This last category can include resistance to climate policies from key stakeholders, shifts in national climate policy or limited coordination between different levels of government, including urban actors.[4] Effective policy coordination among local, regional, and national governments is crucial to leverage cities' roles in accelerating climate transition. In this complex context, broad participation is needed to engage diverse actors and integrate various perspectives for successful transition pathways and science-based policies.[5]

The European Union (EU) highlights the importance of participation and multi-level dialogues in Article 11 of the Regulation on the Governance of the Energy Union and Climate Action (2018/1999). It recognizes local authorities' critical role in sustainable energy policies, exemplified by initiatives like the Covenant of Mayors (CoM), requiring signatories to create and implement Sustainable Energy and Climate Action Plans (SECAP) to reduce emissions and adapt to climate change. In this context, the EUCityCalc project offers the EU City Calculator, a tool to quantify mitigation potentials and explore decarbonisation pathways. It supports cities in refining climate policy through a co-creation process integrating data and knowledge from multiple stakeholders.[6]

This article draws on the pilot cities´ co-creation experiences with the EU City Calculator, exploring how transition pathways are used to present, discuss and validate climate policies, and how stakeholders align with the city's objectives. By analysing these processes, the study provides insights for cities, policymakers, and stakeholders in urban climate action planning, highlighting challenges, best practices, and lessons to promote collaborative sustainable development. Local stakeholders' contributions are essential in designing effective climate strategies, central to co-creation in decarbonisation pathways.[7] This research addresses (i) how co-creation processes, facilitated by the EU City Calculator, contribute to Climate Action Plans (CAP) development and (ii) what lessons are learned from these processes in the pilot cities. The article introduces the role of co-creation in transformation pathways development through modelling tools, outlines a mixed-method and transdisciplinary research approach, presents results, and concludes with recommendations for further research including implementation issues of CAPs. To explore further details about the EU City Calculator, please refer to the supplementary materials provided with this research or visit the project webpage.[8]

Co-creation in climate policy development

The co-creation concept,[9] often synonymously used with co-production, involves active engagement, participation and collaboration between state agencies and citizens, extending beyond consultation to add valuable insights to outcomes.[10] This concept has gained traction in urban planning, policy development, and environmental modelling, which is characterized by multidimensional processes involving knowledge transfer, production, and use.[11] Addressing urban challenges requires cross-sector collaboration and the inclusion of various actors in public policy, enabling joint decision-making.[12] Participation in co-creation platforms can enhance the legitimacy of decisions and innovation in implementing solutions in cities.[13] In climate policy, co-creation engages local actors in decision- making for decarbonisation strategies, crucial for transformative processes toward climate-neutral pathways.[14] This collaborative development of policies, solutions, or initiatives involves various stakeholders, including government entities, the private sector, civil society organisations, and citizens, leading to inclusive, context-specific outcomes with greater buy-in. In climate action planning, co- creation integrates local knowledge, resulting in more effective, sustainable, and adapted solutions.[15] The theoretical foundation of co-creation is rooted in participatory governance, stakeholder engagement, and collaborative decision-making, recognizing that complex challenges like climate change require a holistic approach leveraging diverse experiences, resources, and insights.[16] By fostering co-creation, policymakers and urban planners can ensure that strategies and plans align with local needs and priorities, making co-creation a fundamental characteristic of social innovation for urban climate policy while empowering local communities.[17] Co-creation processes are significantly shaped by social, cultural, and political factors, introducing complex challenges related to governance dynamics and power distribution among stakeholders.[18] While co-creation has the potential to dismantle hierarchies and existing power structures, a critical consideration is the selection and inclusion of participants.[19] The availability and distribution of resources can substantially influence both the process and its representativeness. It is crucial to clearly define and communicate the role of the co-creation process in policymaking from the outset and ensure its realization by the conclusion.[20]

Modelling tools can support co-creation by enabling the formulation of pathways, action plans, and policies. These models facilitate decision-making by incorporating diverse perspectives in collaborative processes, providing scientific insights and exploring scenarios, trade-offs, and interdependencies. They thereby enable cross-sector collaboration and knowledge integration which are prerequisites for transformative changes.[21] However, models require social validation, reflection on concepts and values, and commitment to capacity building. This fosters stakeholder engagement and learnings to generate new scientific and socially robust knowledge.[22]

METHODOLOGICAL APPROACH

The study employs quantitative and qualitative methods to outline the results and feed the discussion (see Table 1). Quantitative results of the co-creation include metrics such as the number of stakeholders involved, measures selected and integrated into the tool, together with the potential emission reductions resulting from the co-creation. Qualitative results are assessed through interviews, project reports, and surveys conducted with city representatives and other stakeholders. Pilot cities provided insights into the local co-creation process, stakeholder engagement, the selection of measures and transition pathways, and the impact of the co-creation process in each pilot city and metrics to compare similarities and differences in success.[23]

Approach	**Criteria**	**Goal**	**Impact on Climate Action**
Quantitative	Number of stakeholders involved	• Cover a broad range of stakeholders represented • Creating responsibility, acceptance and commitment among stakeholders	• Integration of a broad range of expertise and sectors
	Number of measures agreed upon in the co-creation process	• Measures as core elements for transition pathways and foundation of SECAPs • Developing timelines and different scenarios to showcase differences in ambition and impact of measures on climate	• Developing tailored climate measures • Understanding trade-offs and conflicts between measures
	Percentage of CO2-Emissions reduction	• The co-creation sparks discussions for new measures with further emission reductions to the existing CAPs	• Enhanced climate policy through more measures • Validation of existing CAPs
Qualitative	Surveys and interviews with representatives from pilot cities	• Understanding the impact and struggles in developing CAPs through the co-creation process and with the help of the EU City Calculator web tool	• Revising the model itself to tailor it more to the needs of cities • Understanding the advantages and limits of the tool
	Surveys and project reports of pilot cities	• Inquiry of lessons learned in pilot cities in developing SECAPs and transformation pathways	• Scaling the development of SECAPS and enabling the wide usage of the webtool

Table 1. Methodological approach of the paper (authors' own)

Questions in the surveys and interviews were designed to draw out detailed responses encouraging cities to provide concrete examples and experiences. Collected data was analysed using thematic coding for qualitative responses and statistical analysis for quantitative data.[24]

EU City Calculator co-creation process

The co-creation process was designed to collaboratively develop transition pathways for climate policies in pilot cities, actively engaging stakeholders from sectors like local government, industry, and civil society. The methodology created a platform for these groups to develop scenarios and measures together, ensuring outcomes were comprehensive, inclusive, and context-specific.

Pilot cities used a Stakeholder Mapping Tool based on the power/interest matrix and stakeholder management model,[25] to identify and engage relevant stakeholders, forming expert working groups crucial to the process. Groups were organised based on existing synergies and relationships, with some cities utilizing pre-existing organisations and others creating new ones to support the development of transition pathways. The expert working groups typically included public officials responsible for SEAPs/SECAPs and related strategic plans alongside representatives from various sectors such as industry, construction, agriculture, NGOs, and academia. The composition varied by the geographic specificities of the pilot cities such as port authorities in some coastal cities.

The co-creation process, in Figure 1, involved workshops for consensus-building and iterative refinement. Initially, local stakeholders were mapped by administrative representatives to cover broad sectoral expertise and diverse perspectives. In the second and third steps, expert groups explored measures and transformation scenarios. Core workshops involved face-to-face sessions using data- based scenarios from the tool, where participants collaboratively co-designed transition pathways, making consensual decisions on measures and ambition levels while analysing impacts.

Informed decisions were made when diverse stakeholders with different perspectives understood policy trade-offs and conflicts, resulting in experts developing transformation pathways supported by society.[26] The process included introductory sessions to present the project and tool, sector-specific workshops to refine transition pathways, summary sessions to provide a complete city roadmap, concluding with political validation to integrate scenarios into city plans.

Accordingly, emphasis was placed on involving city officials and planners in the decision-making process. As participants mapped measures within the EU City Calculator tool, the process encouraged inclusivity and iterative refinement. In the final stage, public commitments, such as Memoranda of Understanding or monitoring groups, were established to maintain engagement and track progress.[27] Continuous communication and updates were essential to keep stakeholders informed and motivated throughout the process, aligning with best practices in participatory governance.[28] Hence, ensuring stakeholder involvement post-co-creation process is critical for implementing and monitoring proposed measures.

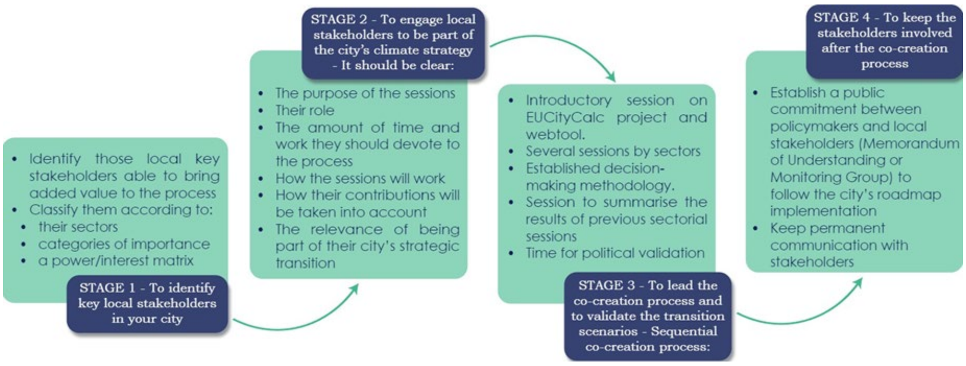

Figure 1. Methodology of the co-creation in the EUCityCalc project

RESULTS AND DISCUSSION OF THE CO-CREATION PROCESS

The impact of the co-creation process can be assessed from various perspectives, including its methodological design, application, and ongoing outcomes, such as stakeholder involvement and transition pathway co-design. Stakeholders appreciated the collaborative approach and the chance to influence climate policy development, but they also noted challenges like data availability and the need for capacity building.

Most pilot cities engaged stakeholders who had not previously been involved in the development of transition pathways. For example, Mantova involved stakeholders of water management and animal husbandry monitoring, while Riga involved citizens, local businesses, and NGOs. In Riga, co-creation activities were central to all city climate plans, emphasising a clear mission and roles, with politicians involved for legitimacy. Dijon engaged smaller organisations previously not involved, while Zdar focused on those with environmental expertise. Stakeholder participation varied; Setúbal and Riga found it straightforward due to tailored invitations, whereas Mantova and Zdar faced challenges, needing attractive events to boost participation. In Setúbal, Palmela, and Sesimbra, co-creation reinforced existing cultures but faced participation challenges in Sesimbra. In Dijon, fears of symbolic co-creation were alleviated by clear communication, emphasising the importance of transparency for sustained engagement.[29] The co-creation process facilitated room to discuss potential impactful measures, highlighting the need to involve new stakeholders and expand emission reduction efforts beyond industry.

Portuguese cities used face-to-face sessions to design pathways and scenarios, followed by a public commitment ceremony and the creation of a Monitoring Group. Mantova organised separate sessions for different stakeholder groups and a final event to integrate their inputs. Selection of measures involved participatory sessions where stakeholders ranked the importance of preselected measures. Factors influencing the selection included local capacity for implementation, time constraints, and the relevance of measures to existing plans. In Setúbal, Palmela, and Sesimbra, short-to-medium term measures with local scope were preferred. In Dijon, the selection of measures was influenced by the priorities highlighted by regional players and the consistency with actual GHG emissions data, while in Zdar, the main criteria were the payback period and availability of financial subsidies. In Zdar, the tool was not used due to existing documentation, but it was useful for a strategic overview when the interaction of measures in different transition pathways was unclear. In Mantova, the measures were influenced by expanding the ongoing city actions, such as bike sharing and renovation of public buildings.

Mechanisms to ensure implementation and monitoring included political validation, public commitment ceremonies, and the creation of monitoring groups. For instance, the "Arrábida Zero Emissões" monitoring group was established to facilitate the implementation and monitoring of transition roadmaps in Setúbal, Palmela, and Sesimbra.

Stakeholder involvement varied across cities (see Table 2). Riga reported 200 participants and 61 entities, while Mantova involved 25 entities. Sectors covered included transport, buildings, energy, and agriculture. The number of measures in transition scenarios also varied between cities; Riga included 46 measures, focusing on transport, while Mantova had 12 across sectors (Figure 2). Dijon included 9 measures, mainly concerning buildings and energy, while Zdar did not create new measures due to the tool's lack of local financial data and subsidies. The GHG emission reduction potential for the selected measures was substantial, with Mantova reporting a reduction of 120 tons CO_2 compared to the reference year 2005. Dijon reported a GHG emissions reduction potential of -24% to -37% between 2022 and 2030, depending on the scenario, while Riga planned to reduce its emissions by a third between 2019 and 2030 (see Table 3). It's important to note that these potential reductions are not directly comparable between cities due to the different baseline years used. This supports the argument that GHG emissions and measures were discussed and selected by each city using the EU City Calculator. However, these numbers do not represent the total emissions reductions, as many cities have implemented additional measures outside the calculations of the tool. Yet, the tool sparked discussions that led to these measures, highlighting its role in shifting the working culture of cities towards developing CAPs.

	No. Stakeholders	No. Entities
Setúbal, Sesimbra and Palmela	76	34
Mantova	63	25
Riga	200	61 and 5 private persons
Koprivnica, Varaždin and Virovitica	13	4
Dijon	43	24
Ždár nad Sázavou	7	7

Table 2. Stakeholders involved.

The co-creation process involved more than 400 actors from 160 entities across ten pilot cities, demonstrating its inclusivity and outreach. While diversity fosters creativity, it also poses challenges in consensus-building, potentially reducing group cohesiveness.[30] The process ultimately resulted in a total of 32 climate measures with over 93 feasible ambition levels, initially selected by expert groups, with the co-creation process sparking discussions for additional measures. Although many measures were assessed, only a few were added due to the project duration, capacities, and applicability constraints. A key outcome of the co-creation process was its ability to trigger discussions for new tailored measures, creating a cultural foundation for ongoing innovation. The quantitative results showed a significant level of stakeholder involvement in the co-creation process.

	Emission reduction in the most ambitious transition scenario in EUCityCalc	Baselines and remarks
Setúbal (PT)	9,5%	2019-2050; considering measures outside EUCityCalc, the reduction is 47%
Palmela (PT)	4,8%	2019-2050; considering measures outside EUCityCalc, the reduction is 30%
Sesimbra (PT)	12,3%	2019-2050; considering measures outside EUCityCalc, the reduction is 57%
Mantova (IT)	53,4%	2019-2050
Riga (LV)	85,0%	2019-2050
Koprivnica (HR)	54,48%	2011-2050
Varaždin (HR)	54,09 %	2011-2050
Virovitica (HR)	52,69 %	2011-2050
Dijon (FR)	98,1%	2019-2050
Žďár nad Sázavou (CZ)	0 (no transition scenario created)	0 (no transition scenario created)

Table 3. Potential GHG emissions reductions in pilot cities in the most ambitious scenario in EUCityCalc. As the model cannot include all possible measures in a city, the complete roadmaps might have higher emissions reductions.

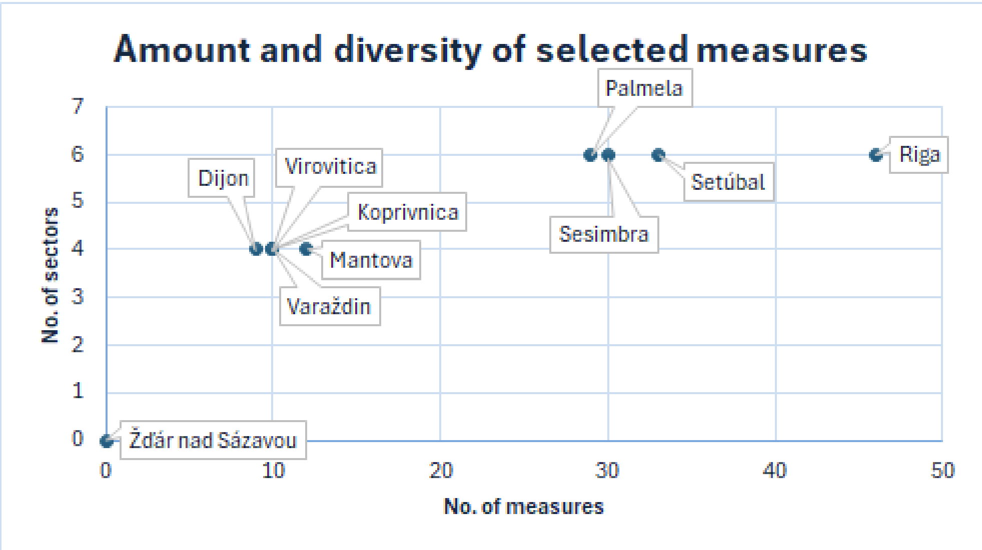

Figure 2. Number of measures and sectors in the most ambitious emission scenarios of different pilot cities.

Co-creation challenges included data availability, tool complexity, and the need for continuous stakeholder engagement and capacity building. Addressing these were crucial for success. Qualitative insights highlighted these challenges and suggested strategies for overcoming them, such as engaging departments through one-on-one meetings like Riga did. Co-creation was seen as beneficial for fostering innovation and social learning. Stakeholders could freely express the reasons for their positions, which was enlightening for decision-makers. Stakeholders and city administrations learned from each other, leading to more ambitious policies,[31] confirming that participatory modelling generates socially robust knowledge by fostering continued learning.[32]

Data collection effectiveness varied. Cities like Setúbal faced challenges in obtaining behavioural data, while others like Mantova did not collect citizen data. This is even though each stakeholder holds specific expertise and knowledge which they could contribute to the process.[33] Innovative approaches included using existing energy matrices and stakeholder surveys. The co-creation process evoked new ideas for measures like an energy poverty fund and the promotion of an innovation cluster in local industries. Our research suggests that the production of new knowledge, skills, and resources due to the engagement of different perspectives remains a key point in the co-creation processes.[34]

Most cities reported fair discussions with equal stakeholders' opportunities. In Mantova, discussions were collaborative and constructive. In Dijon, some participants found it difficult to express their views due to the lack of quantitative sectoral data, but overall, the discussions were fruitful. The process enhanced the quality of measures and stakeholder responsibility for implementation. For example, Setúbal integrated co-creation into its local CAP, while other cities are in the process. The increased ownership and involvement that co-creation can achieve is one of its main benefits,[35] as it makes the attainment of longer-term visions possible.[36] Favourable conditions included transparent communication and high-level stakeholder involvement, while obstacles included data collection difficulties.

Recommendations for future co-creation processes include involving diverse stakeholders from inception, maintaining transparent communication, implementing feedback mechanisms, and considering all perspectives. Stakeholder surveys found the EU City Calculator useful for developing climate policies, appreciating its real-time simulations and scenario visualisations, despite needing more detailed data and complexity for non-technical users.

Overall, the co-creation process effectively engaged stakeholders, fostered innovation, and supported climate action plan development with locally tailored measures. While challenges existed, the overall impact was positive. Insights will refine methodologies and enhance stakeholder engagement in future efforts. The process significantly contributed to developing CAPs, involving stakeholders in scenario and measure development, leading to context-specific policies with broad support. The tool´s maturity at the development stages of the project limited outreach, however, simulations and co-creation helped stakeholders understand decision impacts, leading to informed policymaking.

The process is valued in itself, aligning with trends in public policy and urban planning.[37] Collaborative approaches enable citizens to develop city ownership, empowering them and contributing to successful urban policies.[38] Co-creation is crucial for local climate action development and implementation, generating a new culture in planning, opening communication channels, and enabling transformative changes for climate neutrality. However, its success depends on cities' financial, structural, and cultural contexts.

The co-creation process sparked discussions on integrating new measures tailored to cities' needs, with four measures integrated into the tool. Inclusion was based on data availability, indicators, literature support, timescale, city scale, and tool linkage. While many measures were considered, only a few, particularly in energy and reforestation, were added to the tool, within the project´s timeframe. The process highlighted the need for broader sectoral involvement beyond industry. Findings emphasise that while modelling tools are valuable, they have limitations. Urban spaces vary based on economic, cultural, and climatic factors, requiring specific interventions.

CONCLUSION

The EU City Calculator proved valuable in developing dynamic transition pathways and evidence-based scenarios, enhancing the quality and relevance of CAPs. The reasons lie in the collaborative analytical and deliberative processes that allow diverse local actors to agree on pathways using visualisations.

The co-creation process enhanced the quality and relevance of CAPs in eight out of ten cities while fostering ownership and commitment among stakeholders, crucial for the successful implementation of urban climate policies. It facilitated the integration and update of (SE)CAPs, providing support for policy development. Quantitative and qualitative results demonstrated the tool's potential to contribute to significant CO_2 emissions savings and actionable climate policies. However, monitoring and evaluation mechanisms remain crucial for tracking progress and making necessary adjustments. Ensuring these collaborative efforts beyond the project's duration is essential to maintain momentum and achieve long-term climate goals.

Co-creation processes supported by modelling tools can play a key role in climate policy development by engaging a broad range of stakeholders. These processes can foster the creation of more context- specific measures and cultivate a collaborative culture within cities. This engagement ensures that the strategies developed are aligned with local needs and priorities, enhancing their relevance and effectiveness. The process highlighted the importance of involving new stakeholders and expanding emission reduction efforts beyond industry to include broader sectoral involvement within city administrations. In some cases, weak emission reduction objectives limited the effectiveness of both the tool and the co-creation process. Recommendations for improving future co-creation processes include early diverse stakeholder involvement, transparent communication, and implementing feedback mechanisms.

Our findings suggest that robust local governance structures, local data availability, political commitment, and effective stakeholder engagement significantly influenced the tool's adoption and the co-creation that ultimately can support the successful implementation of transition plans. These insights offer valuable guidance for policymakers and city administrations on leveraging decision-support tools to achieve their climate goals and promote sustainable urban development. Cities showed the importance of mutual validation of different modelling tools to increase confidence, reliability and legitimacy. A single tool proved to be insufficient for decision-making. This strategy helps overcome disagreements about input data and assumptions, a common issue in modelling tool applications.[39] Additionally, the co-creation process facilitates discussions about measures and pathways, fostering a new culture of working within cities. This collaborative approach can lead to commitments that endure through political changes and over time, thanks to stakeholder engagement, transparency, and ownership.

The co-creation process has proven to be a catalyst for developing context-specific measures and engaging a broader range of stakeholders in climate action planning. It demonstrates that while modelling tools provide a foundation, the dynamic nature of urban environments requires tailored approaches. The process can lead to new measures and pathways that cities can adopt, with potential support from national and international funding sources. Co-creation fosters a collaborative culture, which is essential for achieving transformative changes towards climate neutrality. Potential research gaps remain. Effective cross-level communication, balancing long-term models with short-term visions, and ensuring multi-level governance are critical areas that demand further attention. Addressing these gaps is essential for the successful implementation of climate policies and transition plans. These insights can guide future implementation of CAPs in other cities, helping to tailor approaches to specific local contexts.

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ASSESSING PUBLIC PERCEPTION AND ACCEPTANCE OF ARTIFICIAL INTELLIGENCE FOR URBAN CLIMATE ADAPTATION INITIATIVES: A SURVEY STUDY IN GERMANY

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INTRODUCTION

In recent years, the effects of climate change have become increasingly apparent. The number of heatwaves, floods and storms is rising continuously and poses major challenges for humankind. To overcome these challenges, appropriate measures need to be undertaken. As a new, disruptive technology, artificial intelligence (AI) provides significant potential to support decision-makers in the field of climate change adaptation (CCA). However, it is questionable how the public will react to solutions developed in this way as AI with broad application possibilities is viewed sceptically.

This paper addresses the issue of public acceptance of AI applications in the field of climate change adaptation in Germany. A survey study is used to draw conclusions about attitudes towards AI-based technologies deployed in that area. The findings are used to formulate actionable recommendations for decision-makers.

Background

AI is considered as a disruptive technology that already has impacted various sectors.[1] The term AI was coined during the Dartmouth Conference in 1956.[2] Although the term is nearly seventy years old, there is still no uniform definition of AI, but various approaches on how to define AI.[3] For the scope of the survey, the introduction included the short definition “AI is generally understood as technologies that imitate human cognitive abilities”[4] to set a broad starting point without including or excluding specific technologies. To avoid barriers in the deployment of AI systems, it is important to investigate factors contributing to their acceptance.[5] Since its debut in 1989,[6] investigating user acceptance of new technologies has often been conducted with the Technology Acceptance Model (TAM).[7] This model has been applied to several use cases of AI, ranging from traditional agriculture,[8] to the modern field of e-commerce. [9] Although the TAM is focused on the acceptance of system users, its implications can help to draw conclusions for public sector deployment of AI systems as will be shown later.

The field of CCA is relatively new[10] but due to the advancing climate change, it is becoming increasingly important to adapt urban environments.[11] Yet, deploying CCA strategies is met with barriers.[12] Due to the novelty and fast developments of both CCA and AI, there is scarce literature covering the deployment of AI for CCA.[13] AI bears great potential to support combating the impacts of climate change,[14] e.g. in predicting and dealing with climate scenarios[15] or in reducing resulting damages to the ecosystem and humankind.[16]

To reach its full potential, the deployment of AI systems should regard local circumstances and society rather than a widespread implementation.[17] We therefore examine the deployment of such systems on a municipal level.
Since both AI and CCA are presented with barriers upon implementation, the combination of both would be so, too. As we believe that AI technology can be of great use to tackle challenges of CCA, we aimed to find out the acceptance status is in Germany and potentially existing barriers.

METHODS

For the design of the questionnaire, comparable studies were reviewed.
Choung et al. presented their results from two studies on trust in AI and its influence on acceptance of AI technologies. Their findings show that it is important to generate a high level of trust to facilitate the acceptance of such technologies. They furthermore hint that trust could be measured not only in technology but also in governing bodies.[18] Brauner et al. conducted an acceptance study where participants were shown 38 topics about what AI will do. The participants were asked to evaluate the likelihood of the presented developments and their evaluation of the topic on a 6-point Likert-scale. The authors conclude that the perception of AI varies within the wide range of application possibilities. They suggest more targeted rather than broad approaches.[19]
Filho et al. combined a systematic literature review and a questionnaire for exploring connections between AI and CCA. Their findings imply that although the relevance of AI for climate change management is expected to increase in the future and economic and environmental benefits are being anticipated, there is scepticism against AI deployment for climate change measures in policy and governance fields and fears against the technologies in general. This might result in barriers.[20]
The implications have been put under consideration in the creation of our questionnaire.

Research questions

The aim of the study was to identify the drivers of public acceptance towards AI in the public sector for CCA measures. Under this premise, we derived certain research questions (RQs) which we wanted to find answers to through our questionnaire.

RQ1: Does knowledge about AI technologies influence acceptance?

We base this research question on some degree of AI anxiety being prevalent in society.[21] We wanted to find out whether knowledge boosts acceptance or whether it causes anxiety and thus yields negative effects. In their survey about attitude towards AI, which was published after we collected our survey answers, Schiavo, Businaro and Zancanaro added a similar hypothesis and found that AI literacy had a positive effect on AI acceptance while anxiety had a negative effect.[22] Their result can work as a point of comparison for our findings.

RQ2: What impact does trust in regulatory bodies to regulate AI have on the acceptance of deployment in the public sector?

As stated above, AI as a new and disruptive technology faces scepticism. We assume that people are less likely to accept public deployment of such technologies if they do not trust their government to regulate it appropriately.[23] Thus, we aim to find out whether trust in regulatory body influences the acceptance of publicly deployed AI technologies.

RQ3: Is AI in the specific use case CCA more likely to be accepted?

Since the impacts of climate change have grown more evident in recent years,[24] and higher per capita rates can be linked to more climate change concerns,[25] we assume to find great approval for CCA measures in Germany. Hence, we want to see whether our participants are more open for AI technologies when specifically deployed to tackle climate change.

Additionally, we included several questions to identify potential barriers that may come up when AI systems are being deployed in the public sector as well as factors which may have a positive effect on public acceptance of such systems. The findings may help decision-makers to develop implementation strategies that are met with a high level of public acceptance.

Questionnaire design

While the questionnaire was not visibly divided for participants, we separated the questions into four categories. The first category presented questions about AI in general. In the second category, participants' stance towards politics and regulation of AI was queried. The third category targeted the topic of CCA and the precepted role of AI deployment in that area. The fourth category included questions about demographics.

This splitting of questions allowed comparing participants' attitudes under different circumstances and thus was intended to ease drawing conclusions based on the previously mentioned RQs.

In total, the questionnaire consisted of 35 questions: 18 Likert-scale questions, 6 multiple choice questions, 5 open questions and 6 demographic questions. Two Likert-scale questions were asking the user to answer with a specific value, acting as an attention test to remove inattentive respondents.[26]

Data collection

The survey study was conducted online in April 2024. Participants were paid 3.50£ for answering the questionnaire. The average answering time was twelve minutes. In total, 422 participants replied anonymously. Failed attention checks eliminated 14 respondents, leaving 408 viable responses. 145 identified as female, 259 as male and three as diverse. The age ranged from 18 to 73 years with a mean age of 33. 252 respondents live in cities, 71 in suburbs and 85 in the countryside.

RESULTS

For the scope of this paper, only the most important questions will be regarded. Table 1 depicts the questions and corresponding results.

For calculating means and correlation coefficients, we transformed the Likert-scale responds so that a value of 1 represented the left column of Table 1 whereas a value of 5 represented the right column.

AI in General	Do you believe that AI will play a greater role in our everyday lives in the future?	Not at all	Rather not	Partially	Rather yes	Definitely yes
		0	0	15	112	281
	How would you describe your general attitude towards AI?	Very negative	Rather negative	Neutral	Rather positive	Very positive
		3	28	85	238	54
	How would you rate your knowledge of AI?	Very bad	Rather bad	Mediocre	Good	Very good
		1	43	206	133	25
	How would you rate the practical applicability of the current AI systems that you are familiar with?	Very bad	Rather bad	Neutral	Good	Very good
		1	6	125	232	44
Regulation of AI	In your opinion, how important is it that the technical processes of AI and their results are transparent and comprehensible for everyone?	Very unimportant	Rather unimportant	Neutral	Rather important	Very important
		0	8	23	119	258
	Would you like to see greater use of AI technologies in your city/municipality?	Not at all	Rather not	Only in certrain cases	Rather yes	Definitely yes
		6	62	30	222	88
	Do you think artificial intelligence should be regulated?	No		Only in certrain cases	Yes	
		19		46	343	
	Do you trust political decision-makers to regulate AI appropriately?	Not at all	Rather not	Partially	Rather yes	Definitely yes
		52	128	166	54	8
AI and CCA	How important do you consider municipal adaptation measures to the effects of climate change?	Very unimportant	Rather unimportant	Neutral	Rather important	Very important
		8	27	43	183	147
	How satisfied are you with municipal climate policy?	Very unsatisfied	Rather unsatisfied	Neutral	Rater satisfied	Very satisfied
		26	99	186	89	8
	In your opinion, how important is the use of AI in overcoming the challenges of climate change?	Very unimportant	Rather unimportant	Neutral	Rather important	Very important
		8	40	102	202	56
	Would you like to see greater use of AI technologies for CCA in your region?	Not at all	Rather not	Partially	Rather yes	Definitely yes
		7	60	24	230	87
	Do you believe that you yourself would still benefit from the use of AI technologies in CCA if they were used in a timely manner?	Not at all	Rather not	Partially	Rather yes	Definitely yes
		8	56	82	183	79

Table 1. Survey answers

AI in General

The participants believe that AI will play a bigger role in our future lives. 96% of the participants opted for *definitely yes* or *most likely*, while none disbelieved. This implies that people are aware of the technological progress and assume further developments. When asked about their personal attitude towards AI, we experienced a fairly optimistic view. 72% of the participants describe their attitude to be positive while 8% state it to be negative, leaving 20% neutral. This aligns with the findings of Fast and Horvitz who investigated long-term trends in AI acceptance. They conclude that the discussion is generally optimistic.[27] In assessing their own knowledge about AI, the participants seemed to be somewhat reserved with over 50% choosing the mediocre option. The correlation coefficient of self-assessed knowledge with the attitude towards AI is 0.25, showing that knowledge, or at least self-perceived knowledge, had a positive effect on the attitude towards AI. This confirms our RQ 1 and aligns with the findings of Schiavo, Businaro and Zancanaro.[28] When asked to rate the practical applicability of current AI systems they are familiar with, about 68% of participants claim to be satisfied, choosing *good* or *very good*. The results correlate positively with the general attitude (coefficient: 0.36) which is not surprising since personal experiences with AI technologies have been perceived well.

Regulation and AI

This section's first question asked the participants how important transparent and comprehensible results of AI processes are perceived. 92% of the participants regarded this as important. This call for transparency likely stems from the inscrutability of black box AI systems, which can lead people to reject such technologies.[29] This challenge is well known and researched in the field of Explainable AI which aspires to enhance transparency of AI techniques without giving up on performance.[30] When asked whether they would like more use of AI technologies in their municipality, 76% of respondents expressed desire, indicating that the majority of people see great potential in their deployment. The question whether AI should be regulated was answered affirmatively by 84% of participants. Another 11% only wanted regulation in certain cases. The corresponding free-text answers about the scope of application mostly targeted high-risk areas such as health, justice, autonomous vehicles, military and data protection. Such systems will be subject to the European Artificial Intelligence Act (AIA) that came into force on 1 August 2024. This risk-based regulation approach lays down strict rules for high-risk AI systems. Systems that bear too much risk will be banned.[31] The incorporation of AIA requirements into the development and deployment processes of AI systems might also increase public trust in the technologies since monitoring will be conducted. In comparison, on the question whether the participants trust political decision-makers to regulate AI appropriately, answers were less optimistic. Only 15% showed trust in them, whilst 44% displayed mistrust. When combined with the data about desire for more AI technology in their municipality, we receive a correlation coefficient of 0.13, indicating that trust in decision-makers to regulate AI appropriately has a positive effect on whether people want publicly used AI technologies, confirming RQ2. The answers to the subsequent question which asked for reasonings can be divided into three groups:

First, respondents named a general lack of trust in political decision makers. They do not assign politicians enough competence and knowledge in the field of AI technologies. Furthermore, concerns about corruption and politicians putting their self-interest over public interest have been raised. This suits the economic public choice theory, according to which politicians seek to maximize their private utility which can lead to corruption if the expected utility from such action outweighs potential dismissal when being caught.[32]

Second, policy and regulatory concerns could be observed. Participants named inadequate over-regulation and slow processes in comparison to the fast technology development. While the former could restrict innovation and hold back potential advantages of AI technology, the latter threatens developments not being regulated in time and potentially causing harm. Concluding, participants requested expertise in the regulation of AI.

Third, risks and ethical concerns have been brought up. Participants mentioned fear of misuse of AI technologies which might lead to discrimination or political prosecution. Although the fear is understandable given the technological capacities AI offers, such systems are prohibited according to Chapter II, Art. 5 of the AIA.[33] For ethical considerations, the independent High Level Expert Group on Artificial Intelligence published Ethics Guideline for Trustworthy AI in 2019.[34] These measures show high awareness for the matter of AI and the underlying challenges by the European Union (EU) to facilitate AI deployment while protecting citizens.

AI and CCA

This category started off with a question about the precepted importance of municipal CCA. 81% of the participants believe that this topic is important, indicating that people mostly realize the above-mentioned threats of climate change and seek for measures to tackle it. When asked how satisfied they are with municipal climate policy, the responds diverted. While 45% reported to be neutral, 31% were unsatisfied and only 24% satisfied. Since the respondents live in municipalities of varying sizes all over Germany, this distribution might result of different local states of climate policy.[35] 63% of the participants believe that AI is important in overcoming the challenges of climate change while 12% assume it not to be. This shows that people have high hopes in AI to help solving future climate issues, matching the findings of Leal Filho et al.[36] Consequently, 78% of respondents stated that they would want more use of AI technologies for CCA in their region. This goes in line with our findings that CCA is perceived as an important topic, showing a correlation coefficient of 0.74. When comparing the mean value of responses (3.81) with the mean value of the question whether participants would like greater use of AI technologies in their municipality (3.79), only a small difference of 0.02 can be observed, neither confirming nor rejecting RQ3. When asked whether participants believe they would still benefit from the use of AI technologies in CCA if they were used in a timely manner, 64% answered affirmatively. On average, older respondents tended to answer more negatively on the expected profit.

Implications for decision-makers

As stated above, AI holds great potential in overcoming the challenges of climate change. According to our findings, society realizes the emerging threats and is unsatisfied with current climate policy. The role of AI technologies in combating them is viewed positively. Whilst we observed an overall positive attitude towards AI and its municipal deployment, we found a lack of trust in decision-makers to regulate them appropriately. Our findings suggest that AI experts should be brought into the development and implementation processes when planning to use AI technology in the public sector. By training decision-makers to be able to handle such systems and their results,[37] broader public acceptance may be achieved. With the risk based regulatory framework of the AIA, both regional and national governments have an operational starting point. Demanding compliance with the standards set within the AIA in combination with tailored measures for specific use cases such as CCA can lead to a long-time robust implementation of AI technology and realise its full potential.

Furthermore, we observed that people show strong desire for transparency. The explainability of AI systems' results and consecutive decisions can play an important role for public attitude towards AI.[38] Since autonomous AI decisions might have negative impacts on certain groups or the whole society, human supervision should be ensured and the decisions should be published in a comprehensible way to enhance acceptance. By communicating the goals that are to be achieved with the technology, further transparency can be provided to overcome fears of AI.

The correlation between results for whether respondents expect to profit from timely implemented AI technologies for CCA and the respondents' age indicate a J-Curve behaviour with potential negative short-time effects.[39] Such effects should also be considered when opting to use costly technologies, since the long-term effect would need to outweigh the short-term losses obvious enough to prevent public unacceptance.

Limitations

This study has several limitations.

First, our sample of 408 participants is not representative for the German population. We have significant distortions regarding education with 54.5% of our participants holding a university degree, while 18.5% German citizens have such education.[40] In our sample group, 81.3% respondents were under 40 years old and 4% over 60 years old, while 24.5% German inhabitants are under 40 years old and 29.8% over 60.[41]

Second, since we collected the responses online, we excluded people who are not using the internet and thus might be more rejective towards technology in general.[42] This might lead to excessive optimism in our study.

Third, we might not have included all aspects that influence the acceptance of publicly used AI technologies. Further studies may find more causes for public acceptance and since AI is a fast-evolving technology, they also may change over time.

CONCLUSION

AI technology might play a huge role in overcoming the challenges that the progressing climate change poses to humanity. Nevertheless, deploying such systems should be done carefully to ensure safety for society.

This study suggests that when planning to implement AI solutions for CCA measures, decision-makers should communicate goals early and transparent. Since the general attitudes towards AI and CCA were positive, applying the former to enhance the latter can lead to long-term benefits, although initial costs might pose a decrease to the status quo in the short run.

We identified that trust in decision-makers to regulate AI shows room for improvement. It is necessary to consult experts in the field of AI to understand the scope of opportunities or threats and to properly interpret AI generated results. Therefore, politicians should receive trainings to be able to handle various AI systems.

The AIA might also support public perception and attitude towards AI. Since the risk-based approach bans systems with unacceptable risk for harming people and imposes strict rules on AI technology that bear high risk applications, citizens of the EU can be assured that locally applied AI Systems have been inspected and certified.[43]

In conclusion, we would like to emphasize the necessity to communicate the deployment of AI technology early and transparent to make sure that society is aware of what is to be expected from the systems and what measures have been undertaken to protect humankind against negative effects from both climate change and AI made decisions.

NOTES

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EXPLORING THE LINK BETWEEN SOCIOECONOMIC FACTORS AND CO2 EMISSIONS: A CASE STUDY OF THE CHENGDU-CHONGQING ECONOMIC CIRCLE

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INTRODUCTION

Based on the risk of global warming of 1.5°C, near-zero greenhouse gas emissions and sectoral decarbonization have become one of the main development strategies for many countries. [1] As the largest developing country that contributes 31% of the world's carbon emissions in 2020, China has committed to achieving the largest global reduction in carbon emissions intensity within about 30 years. This paper delves into the link between city-level carbon emissions and its driving factors. Focusing on cities in the Chengdu-Chongqing Economic Circle (CCEC), it uses spatial autocorrelation and the Geographically Weighted Regression Model (GWR) to gain insight into these links in each separate region. In so doing, more specific and practical policy recommendations can be created.

City-level Carbon Emissions Accounting

Urban carbon emissions accounting includes direct carbon emissions, energy indirect carbon emissions and other indirect carbon emissions. Currently, the two mainstream carbon accounting methods are the production-side carbon accounting method (PBA) and the consumption-side carbon accounting method (CBA). The former one divides regional carbon emissions into four sectors, while the latter one is derived from the Economic Input-Output model (EIO) and includes indirect carbon emissions.[2]

Urban carbon accounting methods vary worldwide. While London is one of the few cities using CBA, China and Japan mainly implement PBA based on the Intergovernmental Panel on Climate Change (IPCC) modeling.[3] Mei, Z. et al. used PBA to estimate carbon emissions in energy consumption, industrial production and waste in Chinese cities, finding that eastern cities accounted for over half of the total national carbon emissions. [4] Xu, X. et al also found that 18 central cities contributed 13% to China's carbon emissions in energy consumption from 2000 to 2014.[5] Cong et al. compared five accounting methods for energy consumption carbon emissions, which indicated that different selection of activity coefficient data have a huge impact on the results.[6] Due to the limited applicability of IPCC model and incomplete data in Chinese cities, the consistency and the accuracy of the estimation need to be further improved.

Spatial Correlation and Differences

The spatial dimension stands as an important trait of cities and an underlying factor influencing carbon emissions. Commonly used spatial measurement models include the Ordinary Least Squares regression model (OLS), Geographically Weighted Regression model (GWR), and more generalized Multi-scale Geographically Weighted Regression model (MGWR). To put it more specific, OLS is a linear non-spatial regression model without introducing spatial distance weights, while GWR acts as an improvement. In addition, before using spatial measurement models, spatial autocorrelation needs to be tested through Moran's I index method. Wang, S.J. et al. found the evolution of carbon emission in Chinese cities has obvious spatial effects, with neighboring cities influencing each other. [7]

Socioeconomic Factors and Impacts

Three theoretical models are mainly used to study socio-economic factors affecting urban carbon dioxide emissions, namely Kaya, Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) and the input-output model, respectively. [8] Among the many exponential decomposition analysis (IDA) methods derived from Kaya model, the Log Mean Dichotomous Index Method (LMDI) is recognized as the best for it has no residuals and effectiveness in preventing pseudo-regression problems. This method breaks down carbon emission drivers into the following factors: population size, economic development, industrial structure, energy intensity and energy structure. [9] Relevant studies have found that economic development has a contributing effect on carbon emissions, while the energy structure and population urbanization show an inverted U-shaped relationship with carbon emissions. In addition, urbanization of public services helps reduce carbon emissions. [10]

Research Significance and Innovation

In summary, although there has been a certain degree of research depth and results, research gaps still exist: (1) Due to incomplete energy consumption data in Chinese cities, most research focuses on national or provincial levels rather than city-level emissions; (2) Underdeveloped cities in the western region are often left behind, as current studies tend to focus on major developed cities in the Pearl River Delta and the Pan-Yangtze River Delta; (3) Existing studies mostly conclude spatial autocorrelation of the whole region, lack explanation of local spatial relationship and spatial heterogeneity.

To address these gaps, this paper first estimates the urban carbon emissions of 18 cities in the CCEC from 2012 to 2021 using the PBA methodology. Secondly, it employs OLS regression model to identify overall drivers of city-level carbon emissions, and then GWR model to provide a separate parameter set for local drivers. Last but not least, decarbonization strategies for CCEC cities are proposed.

MATERIALS AND METHODS

Case Choice

The Chengdu-Chongqing Economic Circle (CCEC) is located in western China and acts as one of the main channels connecting international and domestic markets. It covers 16 major cities of Chongqing and Sichuan province, with a total area of 185,000 square kilometers and a total population of over 98 million. In 2021, GDP of this area reached 7391 billion, accounting for 6.5% of the national gross domestic product. [11] In this paper, 18 cities in and around the CCEC are defined as the study area, as is shown in Figure 1.

Figure 1. Study Area in and around CCEC.

Estimating CO_2 Emissions in Chengdu-Chongqing Economic Circle

In this study, PBA is used to account for carbon emissions from energy consumption in CCEC cities. Comprehensive energy consumption includes different types of coal, coke, gas, fuel, oil, heat and electricity, etc. In China, energy is measured in 'Standard Coal,' whose calorific value is 29,307 kilojoules per kilogram. As such, based on the methodology provided by IPCC, the formula for calculating carbon dioxide emissions from comprehensive energy consumption in units of standard coal is:

$C_{energy} = E \times NCV \times CEF \times COF$ (1)

Where C_{energy} represents the carbon emission of standard coal, E denotes the consumption amount of standard coal, NCV denotes the average net calorific value of standard coal, CEF is the carbon emission factor of calorific value unit of standard coal, and COF is the carbon oxidation factor of standard coal, with a default value of 1. The values of each parameter are derived from the General Rules for Calculating Comprehensive Energy Consumption (GB/T 2589-2008) and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

The Geographically Weighted Regression Model and Spatial Autocorrelation

GWR is a method used for local linear regression that considers spatially varying relationships. What should be noticed is that, it focuses on observations close to a specific point and gives more weight to nearby data than to data farther away. The model is represented by the following equation:

$y_i = \beta_0 (u_i,v_i) + \Sigma_j \beta_j (u_i,v_i) x_{ij} + \varepsilon_i$ (2)

where i = 1, 2, … n, (u_i,v_i) represents the spatial coordinate of the i^{th} observation point; $\beta_0 (u_i,v_i)$ is the local intercept of the i^{th} observation point; $\beta_j (u_i,v_i)$ is the parameter of the j^{th} independent variable x_{ij}; ε_i is the random error term.

Besides, GWR model also embeds spatial autocorrelation, which refers to a certain degree of spatial interaction between geographic phenomena or an attribute value among spatial units. Moran's I is divided into global autocorrelation and local autocorrelation. Global autocorrelation identifies and measures the spatial pattern of the whole area:

Moran's I = $\Sigma^n_{i=1} \Sigma^n_{j=1} W_{ij} (Y_i-Y) (Y_j-Y) / S^2 \Sigma^n_{i=1} \Sigma^n_{j=1} W_{ij}$ (3)

where $S^2 = \Sigma^n_{i=1} (Y_i-Y) / n$, $Y = \Sigma^n_{i=1} Y_i / n$, Y_i denotes the observation value of the i^{th} region (e.g., urban carbon emission in this study), n is the total number of regions, and W_{ij} is the binary proximity spatial weight matrix, which is used to define the proximity of the spatial objects to each other. The value of the global Moran's I ranges from -1 to 1. If its value is greater than 0, the larger the value is, the stronger the positive autocorrelation of the spatial distribution is. When its value is less than 0, it indicates differences. if its value is 0, the space obeys a random distribution. Local spatial correlation is the spatial relationship between a single spatial unit and the surrounding ones. The analysis of local spatial correlation mainly includes local Moran's I index and local Geary index, which are defined as:

Moran's $I_i = Z_i \times \sum_{j=1}^{n} W_{ij} \times Z_j$ (4)

where $Z_i = x_i - x$, $Z_j = x_j - x$, denote deviation of the observed value and the average value respectively, x_i denotes the observation of spatial unit i, and W_{ij} denotes the spatial weight matrix.

Socioeconomic Factors

In this study, eight variables were selected according to the existing literature and they are grouped into four categories. GDP per capita (denoted as PCGDP) is chosen to represent economic growth; Imports and exports (denoted as IE) stands for trade. GDP share of the secondary industry (denoted as IS) represents industrial structure. Total electricity consumption (denoted as EC) acts as an indicator of energy intensity. Population density (denoted as PD), road density (denoted as RD), public transportation passenger volume (denoted as PT) and urban expansion (denoted as UE) are chosen to represent urbanization. The descriptive statistics of the above variables are summarized in Table 1.

Variable	Abbreviation	Unit	Category
GDP per capita	PCGDP	unit of money (in PRC: Chinese yuan)	Trade and economy
Imports and exports	IE	ten thousand dollars	Trade and economy
GDP share of the secondary industry	IS	percentage	Industrial structure
Total electricity consumption	EC	kilowatt-hour (kWh)	Energy intensity
Population density	PD	persons per square kilometer	Urbanization
Road density	RD	percentage	Urbanization
Public transportation passenger volume	PT	ten thousand persons	Urbanization
Urban expansion	UE	square kilometer	Urbanization

Table 1. Socioeconomic Factors Selection.

Database

Comprehensive energy consumption data and socioeconomic driver data were sourced from China Urban Statistical Yearbook (2012-2021), as well as from Sichuan Provincial Statistical Yearbook, Chongqing Municipal Statistical Yearbook, and each city's statistical yearbook. Any missing data were filled in using interpolation methods.

DATA RESULTS

Moran's I

As for CCEC cities on a whole, the value of Moran's I index is 0.057361 with a p-value of 0.018189, indicating positive spatial autocorrelation, i.e., similar values tend to cluster spatially. These results emphasize the importance of considering spatial dependencies when formulating carbon abatement policies, as different regions may require tailored approaches based on their specific emission patterns. Figure 2 shows the results of Moran's I analysis.

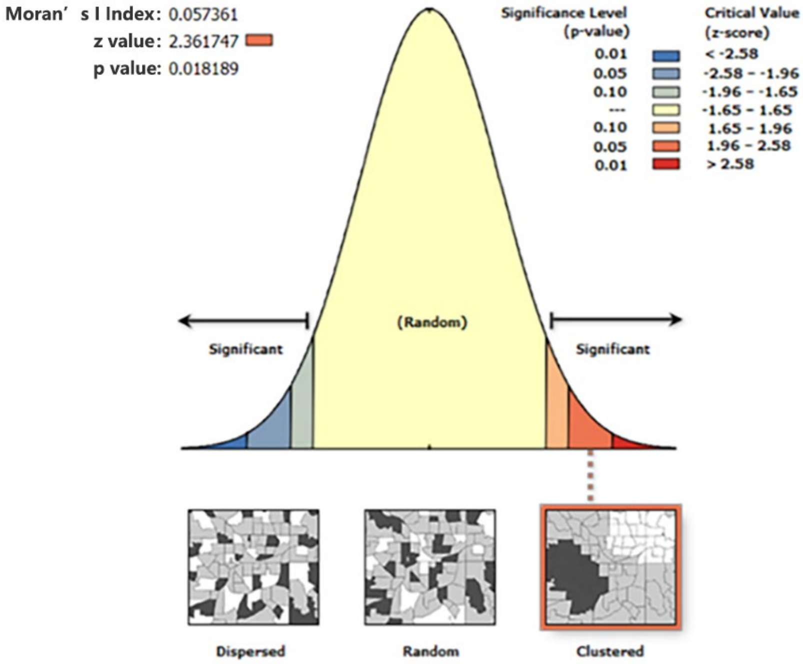

Figure 2. Moran's I Analysis Results.

OLS Results

Over the period from 2012 to 2021, the OLS model result consistently shows a significant relationship between certain variables and carbon emissions. Among them, the GDP share of the secondary sector, population density and total electricity consumption boasted a strong positive impact with significant coefficients and low p-values. Public transportation passenger volume also had a positive impact, though less strong. On the contrary, GDP per capita showed a negative correlation, with a significant coefficient and low p-value. Road density and urban expansion showed some negative correlation. Imports and exports exerted a non-significant and unstable impact, showing a weak positive correlation in the first 5 years and a weak negative correlation in the latter. Details of the OLS results for 2015, 2017, 2019, and 2021 can be found in Table 2.

Variable	Coef	StdError	t_Stat	Prob	Robust_SE	Robust_t Value	Robust_P Value	VIF
Intercept	1.322	2.787	0.474	0.647	2.914	0.454	0.661	———
PCGDP	-2.135	0.668	-3.197	0.011	0.547	-3.901	0.004	5.076
IE	0.188	0.121	1.551	0.155	0.125	1.507	0.166	5.270
IS	2.593	1.458	1.778	0.109	1.093	2.372	0.042	2.167
EC	1.547	0.405	3.825	0.004	0.296	5.230	0.001	19.536
PD	1.287	0.359	3.584	0.006	0.365	3.531	0.006	4.104
RD	-0.190	0.222	-0.857	0.413	0.246	-0.772	0.460	3.975
PT	0.059	0.135	0.437	0.673	0.090	0.651	0.531	4.037
UE	-0.980	0.558	-1.757	0.113	0.472	-2.076	0.068	24.907

Table 2. OLS results for 2015.

Variable	Coef	StdError	t_Stat	Prob	Robust_SE	Robust_t Value	Robust_P Value	VIF
Intercept	-17.215	14.123	-1.219	0.269	12.435	-1.384	0.216	—
PCGDP	-0.286	0.353	-0.811	0.448	0.173	-1.658	0.149	1.193
IE	-0.147	0.688	-0.213	0.838	0.369	-0.398	0.704	13.849
IS	1.744	4.061	0.429	0.682	2.499	0.698	0.511	2.142
EC	1.815	1.397	1.299	0.242	1.027	1.767	0.128	10.841
PD	4.153	1.919	2.164	0.074	2.150	1.932	0.102	7.735
RD	-2.393	1.084	-2.207	0.069	1.481	-1.616	0.157	6.252
PT	3.528	1.520	2.321	0.059	1.936	1.822	0.118	25.516
UE	-4.779	2.407	-1.985	0.094	3.022	-1.581	0.165	32.547

Table 3. OLS results for 2017.

Variable	Coef	StdError	t_Stat	Prob	Robust_SE	Robust_t Value	Robust_P Value	VIF
Intercept	2.543	4.436	0.573	0.587	3.627	0.701	0.509	—
PCGDP	-2.644	1.206	-2.193	0.071	1.095	-2.415	0.052	15.654
IE	-0.019	0.265	-0.073	0.944	0.179	-0.108	0.918	34.489
IS	2.986	0.638	4.682	0.004	0.596	5.010	0.003	1.397
EC	1.546	0.361	4.280	0.005	0.257	6.009	0.001	14.848
PD	0.464	0.361	1.286	0.246	0.153	3.044	0.023	5.063
RD	-0.335	0.288	-1.162	0.289	0.218	-1.538	0.175	9.524
PT	1.165	0.335	3.478	0.013	0.255	4.560	0.004	19.698
UE	-1.265	0.670	-1.887	0.108	0.529	-2.390	0.054	49.500

Table 4. OLS results for 2019.

Variable	Coef	StdError	t_Stat	Prob	Robust_SE	Robust_t Value	Robust_P Value	VIF
Intercept	-6.515	6.767	-0.963	0.361	6.494	-1.003	0.342	—
PCGDP	-0.032	1.710	-0.019	0.985	1.309	-0.024	0.981	11.848
IE	-0.193	0.311	-0.621	0.550	0.318	-0.608	0.558	16.421
IS	1.180	1.204	0.980	0.353	1.040	1.135	0.286	2.095
EC	1.520	0.477	3.189	0.011	0.504	3.016	0.015	8.597
PD	1.710	0.797	2.145	0.060	0.618	2.767	0.022	9.445
RD	-1.411	0.833	-1.693	0.125	0.636	-2.219	0.054	19.757
PT	0.441	0.396	1.112	0.295	0.320	1.378	0.201	13.906
UE	-0.377	0.743	-0.508	0.624	0.328	-1.149	0.280	22.120

Table 5. OLS results for 2021.

GWR Results

R^2

The r-squared (R^2) values of the GWR model range from 0.51 to 0.99, which indicates that the model fits the data well. The darkest red color represents the highest r-squared value, which suggests the regions where the model fits best. R-squared values of the regression model gradually increased in the first five years, reaching the minimum of 0.52 and the maximum of 0.98 in 2017 and then decreased to around 0.85. Overall, the model fits best in cities in the southwest and less well in the northeast.

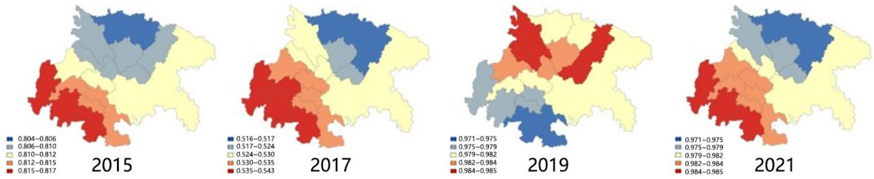

Figure 3. Local R^2 results for 2015, 2017, 2019, 2021.

GDP per capita

In Figure 4. (a), the different shades of colors reveal the extent to which GDP per capita (PCGDP) contributes to carbon emissions in different cities. Dark blue shades in northeastern regions such as Dazhou, Bazhong and Guangyuan, indicate that PCGDP had a greater negative impact on carbon emissions compared to cities in the southwest of CCEC.

From the time span, the negative impact of PCGDP on carbon emissions gradually intensified during 2012-2016. After a brief reduction in 2017, the negative impact intensified again and even turned positive in southwestern CCEC cities such as Ya'an, Leshan and Yibin.

Imports and exports

It can be seen from Figure 4. (b) that between 2012 and 2017, the total imports and exports of the cities in the northeast showed a positive correlation on carbon emissions, reflecting that foreign trade in these cities was relatively more developed, and the import and export industry had a greater impact on carbon emissions. Since 2018, imports and exports turned to have a negative impact, which was more pronounced in the southwestern cities.

GDP share of the secondary industry

In Figure 4. (c), The area with darker red color shifted from the northeast to the west. In 2012, cities with intensive energy-consuming industrial activities, such as Chongqing, Dazhou, and Guang'an in the eastern region, produced relatively more carbon emissions. By 2015, the contribution of the southwestern cities exceeded that of the east. Nonetheless, in general, there wasn’t a significant geographic difference among the CCEC cities in any given year. And the positive impact of the secondary industry GDP share on carbon emissions gradually decreased over the entire period.

Total Electricity Consumption

Figure 5. (d) demonstrates how total electricity consumption positively impacted urban carbon emissions. In the first five years, its impact was geographically unstable but then significantly positive in the second five years in the eastern cities, especially Chongqing. Throughout the ten years, the positive contribution rose steadily, which may be a result of rising energy demand.

Population density

As it is shown in Figure 5. (e), from 2012 to 2016, the positive influence of the northeastern region exceeded that of the southwest, and the gap was small. However, in the latter five years, the positive influence became more significant in the southwest, and the gap between the regions widened.

Road density

Figure 5. (f) demonstrates that in 2012-2016, western region showcased more significant negative impact. After 2017, the negative impact in the northeastern region decreased and even turned positive.

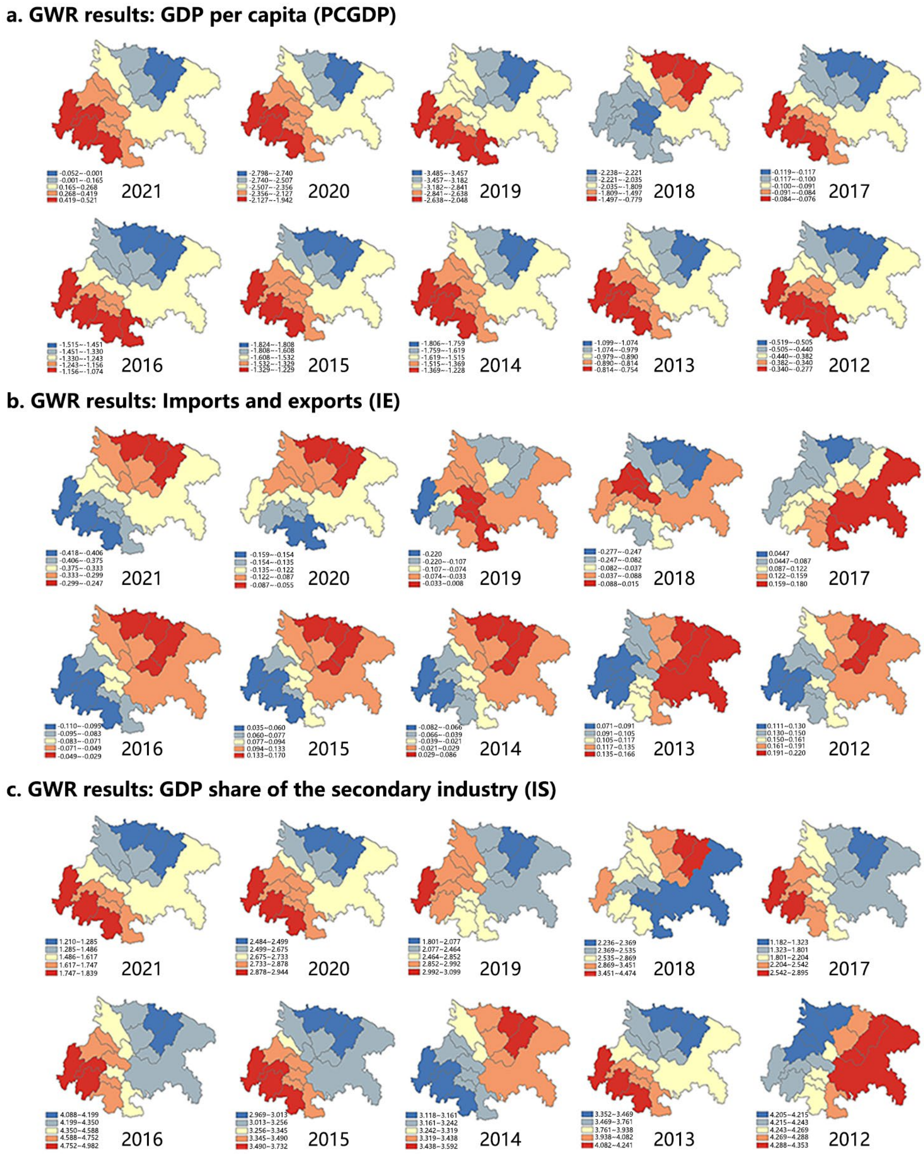

Figure 4. GWR results from 2012 to 2021 (Included drivers: PCGDP, IE, IS).

Public transportation passenger volume

The area with dark red color in Figure 6. (g) shifted from the southern region to the north-central region, i.e., the positive contribution of public transportation passenger volume to carbon emissions had a geographic tendency to shift from south to north. The time series analysis shows that the positive influence increased during the period of 2012-2017, but then decreased after 2019.

Urban expansion

In Figure 6. (h), the negative contribution of urban expansion was not stable between 2012 and 2021, with more significant negative impacts mainly in the southwestern region. The negative impact of urban expansion experienced an increase during 2012-2017 but dropped during 2018-2021.

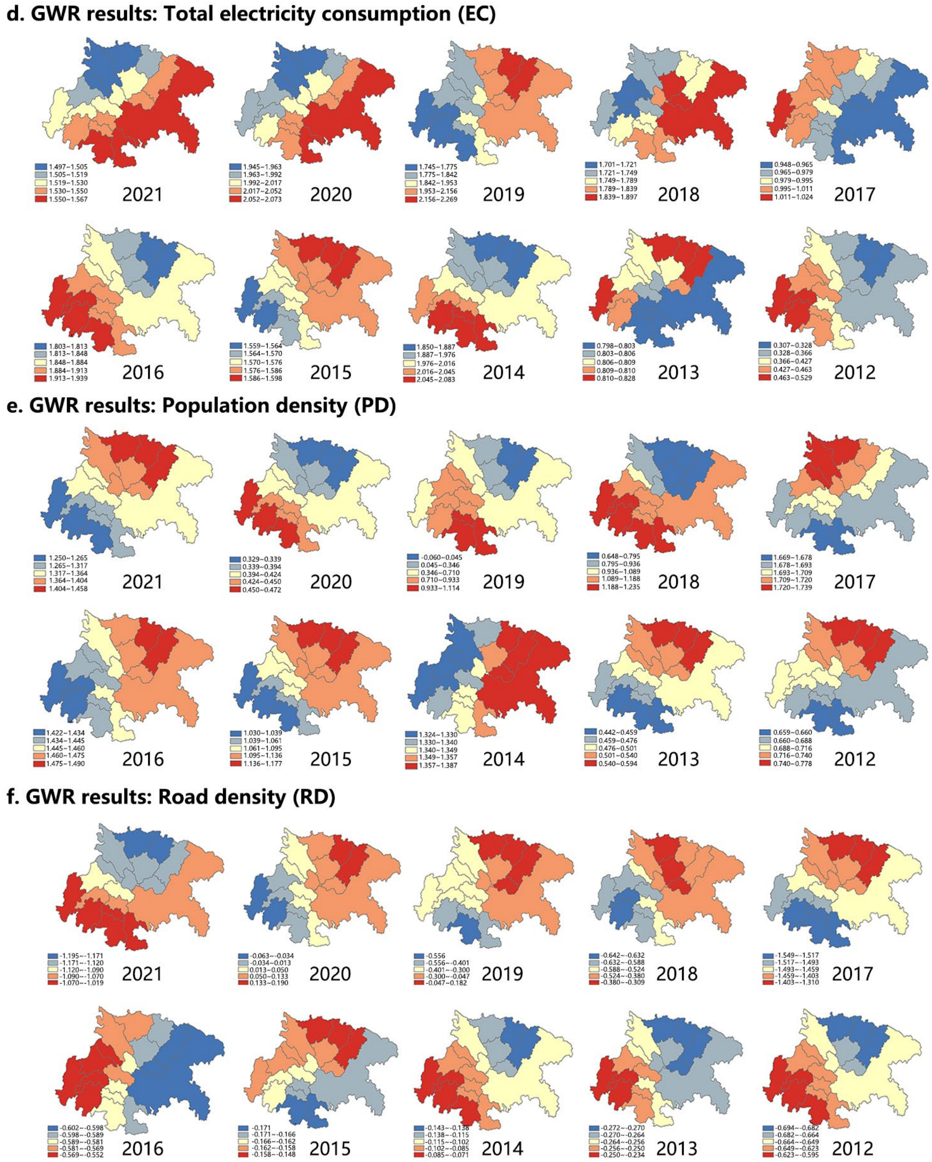

Figure 5. GWR results from 2012 to 2021 (Included drivers: EC, PD, RD).

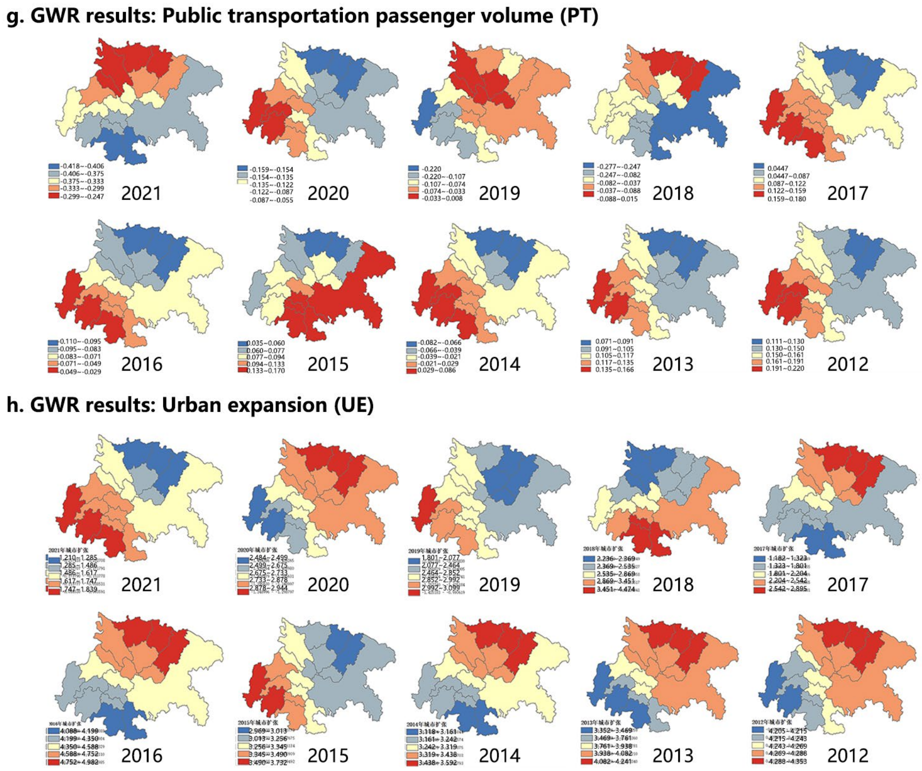

Figure 6. GWR results from 2012 to 2021 (Included drivers: PT, UE).

POLICY RECOMMENDATIONS

As it's shown in Figure 7, to realize sustainable urban development and effectively respond to climate change in the CCEC, it is more than necessary to consider the effect of multiple socioeconomic factors and propose policy recommendations in a comprehensive manner.

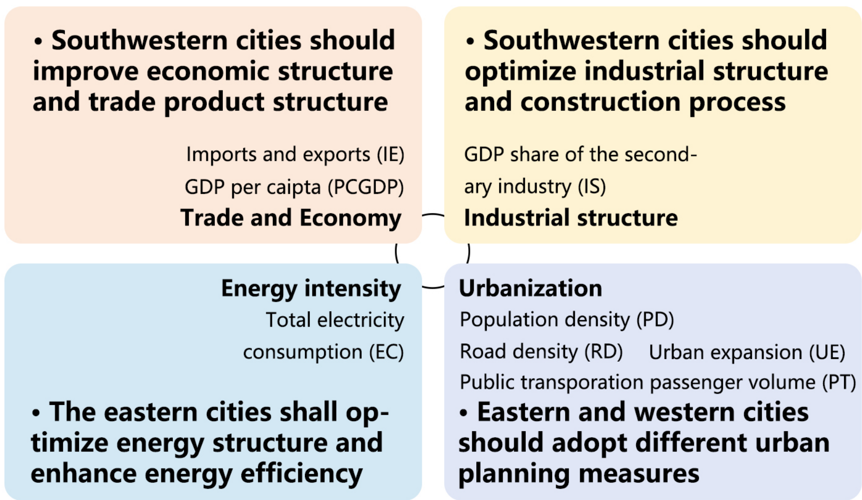

Figure 7. Policy recommendations according to socioeconomic factors.

Trade and Economy

As for trade and economy, its negative impact on urban carbon emissions was more significant in the northern region. Southwestern cities like Chengdu can promote low-carbon economy and establish a carbon emissions trading market system. Noticeably, northeastern cities, which have long supplied energy-consuming products to foreign regions, have become an "implied carbon" transfer area. Local governments can support the development of low-carbon import and export trade through financial subsidies and green credits. [12]

Industrial Structure

The positive impact of industrial structure continued to decline from the southwestern region to the central-northern region. This trend gives credit to the adjustment of industrial structure over the past decade, and further urges for transformation from a traditional secondary industry to a greener one, and an increase proportion of the tertiary industry. On the one hand, cities in the southwest should focus on strengthening light industry and technology-intensive industries. On the other hand, central and northern cities should develop high-tech industries, in order to reduce current over-dependence on heavy industries. In addition, when it comes to construction sector, using energy-saving composite materials and intelligent construction techniques can optimize the entire lifecycle of buildings.[13]

Energy Intensity

The positive impact of energy intensity was stronger especially in the eastern cities of Chongqing, Guang'an and Dazhou. This phenomenon is related to their well-developed grid infrastructure and high electricity demand. Beside energy intensity, energy efficiency should also be improved in combination with economy transformation and industrial structure adjustment. Since the CCEC has a natural advantage in natural gas and hydropower, governments should tailor their policies to local conditions and provide financial subsidies to develop clean and sustainable energy sources.[14]

Urbanization

Overall, the positive impact of urbanization was stronger in the southwest than in the northeast. The increase in road density and urban expansion helped reduce carbon emissions, especially in the northwestern region compared to the eastern region. Therefore, effective land use planning and multi-public transportation services should be implemented. On the contrary, the increase in population density and public transportation passenger volume increased carbon dioxide emissions, and this situation was particularly obvious in the southwest region. Local governments should rationalize and control urban expansion and encourage low-carbon travel.[15]

CONCLUSION

This paper reveals the spatial and temporal evolution characteristics of carbon emissions in 18 cities in the CCEC, identifies the impact of socioeconomic factors through OLS and GWR models. Building upon these insights, it proposes differentiated emission reduction strategies. Moreover, the realization of emission reduction goals of the CCEC requires joint efforts of policymakers, researchers and society.

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DECARBONIZATION THROUGH PERFORMATIVE STRATEGIES IN URBAN CITIES

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INTRODUCTION

As cities strive to reduce their environmental impact, they are increasingly adopting strategies to electrify their building stock. One key mechanism for this transformation is the shift from prescriptive to performative greenhouse gas (GHG) emissions reduction targets. A prime example is New York City's Local Law 97 of 2019 (LL97) which mandates that buildings over 25,000 ft² reduce their GHG emissions by 40% by 2030 and 80% by 2050, from the base year of 2005.[1] This paper examines LL97's strengths and weaknesses in its effectiveness in electrifying the building stock, as LL97 boasts a beneficial electrification credit ("BE Credit") rule which exchanges emissions limits for electrification,[2] as well overall emissions reduction. It also explores the role of educational institutions in supporting such decarbonization projects.

LITERATURE REVIEW

Urban decarbonization strategies

Decarbonization, and by extension climate change mitigation, is subject to both monocentric and polycentric approaches. Monocentric approaches include global policy approaches such as the Kyoto protocol[3] and the Paris agreement,[4] which have been criticized for their inability to fully address the climate crisis. Polycentric approaches have been suggested to supplement the global polycentric policy solutions with a form of localized collective action.[5] Cities are pioneering these approaches, such as the C40 Cities Climate Leadership Group of 40 participating and 19 affiliate cities, including New York City—with 80% of its emissions from buildings—a leading case.[6]

Urban decarbonization strategies are diverse in scope, methods, and goals. Cities principally target the electricity, transportation, waste carbon sinks and storage, as well as buildings.[7] Plans from leading cities emphasize capacity building, leading by example, financial incentives, building standards, and benchmarking and reporting as their main policy instruments.[8]

Buildings are particularly important for decarbonization. The building sector accounted for 31% of total global final energy use, 54% of final electricity demand, and 8% of energy related CO_2 emissions.[9] Moreover, of the industry, transport, power generation, and buildings sector, the buildings sector has the largest unrealized energy efficiency economic potential.[10]

Performative vs. prescriptive

Relevant policies use prescriptive and performance methods. While generally heterogeneous, building energy codes tend to have both.[11] Prescriptive regulations dictate actions to be taken to improve performance, while performance-based regulation (PBR) sets a goal without specifying methods.[12] A resulting key benefit of PBR is greater flexibility on the part of regulated entities, i.e.: PBR creates incentives influencing but not enforcing decision-making.[13]

While PBRs do not inherently induce innovation—the technology and capabilities for change must already be present—PBR does facilitate greater innovation on the part of firms thanks to regulatory flexibility.[14] However, enforcement of accountability is potentially subject to bias in PBR, as it selects metrics easier to observe, thus either rendering enforcement biased or increasing the costs of observing the target variable.[15] In contrast, prescriptive regulation leads to regulation that is easy to enact but with worse results.[16] Nonetheless, the flexibility of PBR can lead to uncertainty or higher costs among firms that are uncomfortable or ill prepared for the methodological ambiguity of PBR.[17]

Role of educational institutions in supporting decarbonization efforts

The substantial GHG reductions required by LL97 present a significant opportunity for specialists to assist buildings in meeting their emissions goals. Compliance pathways under LL97 include the creation of energy storage systems for peak demand periods, building electrification, enhanced roof and pipe insulation, development of on-site solar power, renovation of building façades to Passive House standards, upgrades to ENERGY STAR® appliances, and the installation of LED lighting with controls. The Mayor's Office of New York City estimates that full compliance could generate 140,000 new jobs.[18]

To meet NYC's GHG standards, educational institutions must equip students with both existing and emerging skills. Key areas include environmental and mechanical systems, façade design, and renovation expertise. Given that LL97 is a PBR with no prescribed approach, a broader range of knowledge and skills is necessary to achieve compliance. Many of these pathways require specialized, customized strategies, which alone may not suffice. Therefore, new research is essential to discover additional methods for efficiently reducing building GHG emissions. This integration of research with practical implementation offers research institutions a unique opportunity to develop techniques and provide hands-on experience.

LOCAL LAW 97: OBJECTIVES AND IMPLEMENTATION

LL97 is a landmark piece of legislation passed by the New York City Council in 2019 as part of the city's broader Climate Mobilization Act.[19] The law represents one of the most ambitious efforts in the United States to reduce greenhouse gas (GHG) emissions from buildings, which are the largest single source of emissions in the city, accounting for nearly 80% of its total emissions.[20] The primary objective of LL97 is to reduce citywide GHG emissions by 40% by 2030 and 80% by 2050, relative to 2005 levels.[21] These targets are aligned with the broader goals of the Paris Agreement, aiming to limit global warming to well below 2 degrees Celsius.

LL97 targets large buildings over 25,000 square feet, which includes approximately 50,000 buildings across New York City.[22] The law sets specific GHG emissions intensity limits, expressed in kilograms of CO2 equivalent per square foot, which buildings must not exceed. These limits are progressively tightened over time, with initial caps beginning in 2024, becoming more stringent by 2030, and continuing through subsequent compliance periods. Renewable Energy Credits (RECs) allow the trade of RECs purchased from excess renewable energy for GHG limits. With recent large renewable energy projects such as the Clean Path NY project and the Champlain Hudson Power Express project there will be an overabundance of RECs which could dilute the effectiveness of LL97.[23]

LL97 addressed the issue of methodological ambiguity of PBR with the NYC Accelerator which assists with compliance and provides free expertise specifically for LL97 along with other city initiatives.[24] This addresses ambiguity and uncertainty among firms and building owners regarding the options to achieve LL97 goals.

Buildings that exceed their allowable emissions are subject to financial penalties, which are calculated as $268 per ton of CO2 equivalent over the limit. The law also allows for certain adjustments and exceptions, including hardship provisions for buildings that can demonstrate that compliance would cause undue financial strain, as well as provisions for if a state of emergency is declared by the NYC Mayor wherein the effect of LL97 is put on pause.

Success will depend on the effectiveness of its enforcement, the willingness of building owners to invest in necessary upgrades, and the ability of the city's infrastructure to support widespread electrification and renewable energy adoption.

ANALYSIS OF LL97'S EFFECTIVENESS

Examination of emissions reduction data

Using data from LL84, a precursor law to LL97 requiring buildings to report their emissions along with other data, we can obtain data on nearly all the buildings in NYC over 25,000 square feet. This data had several duplicates and other issues, but once processed we had 196,401 observations in total over an 11-year period from 2010-2020. While there are approximately 250 variables reported in total, we focus on those related to LL97. As such, we can see GHG emissions over the past decade per building in figure 1, along with the mean ghg emissions for all buildings per year. This reveals that there is a downward trend, although the distribution is difficult to discern due to the volume of the data.

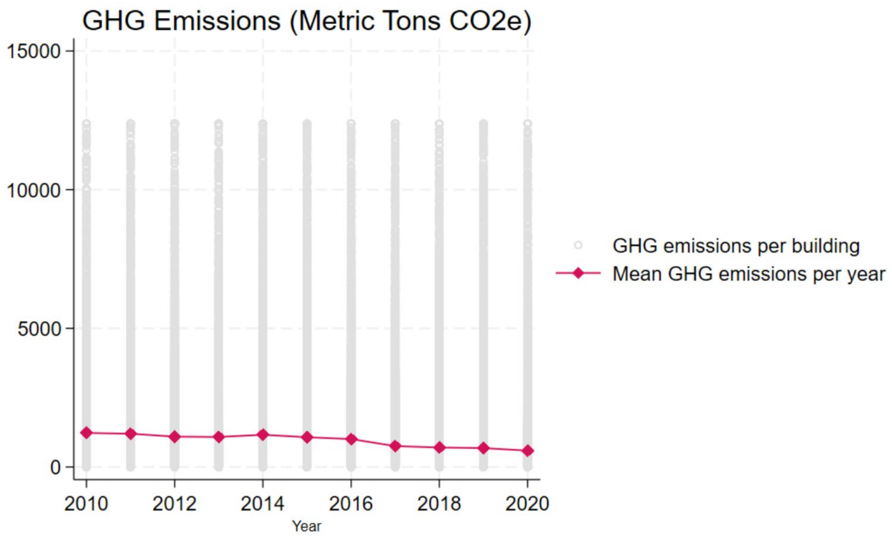

Figure 1. NYC GHG emissions 2010-2020

Buildings in NYC generally have a very wide range of GHG emissions, which can be seen in more detail in figure 2.

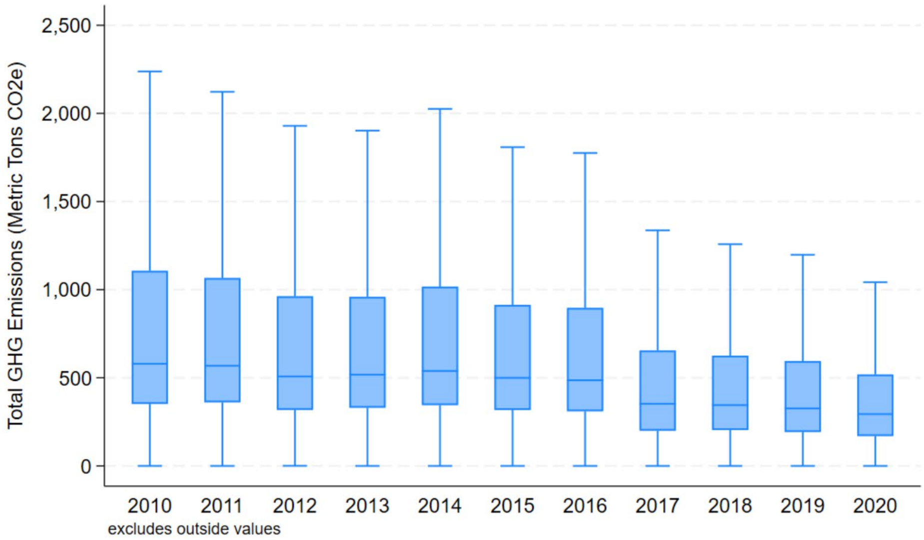

Figure 2. Boxplot of GHG emissions 2010-2020.

The greatest change is in the upper half of emitting buildings, in comparison to the change in the lower half of emitting buildings. This can be explained by the pressure of LL97 and other related measures of NYC, as they penalize the larger emitters the most, while those closer to carbon neutral, or even those barley below the threshold for fines, will not have as much of an incentive to reduce emissions. While this trend may validate the effectiveness of LL97 in reducing emissions, it does raise questions as to its ability to reduce emissions in buildings with a lower baseline.

Since LL97 mandates certain reductions relative to base emissions from 2005, those with already low emissions will have a low bar to clear, despite possibly having room as well for changes in emissions that are not insignificant as most of the buildings are in the lower range of GHG emissions. Since the key concern of LL97 is to affect future emissions, and since it is relatively recent, most of the historical data from 2010-2019 would of course not have been impacted by LL97. As such, we projected the trend of individual building's GHG emissions up into 2050 in figure 3.

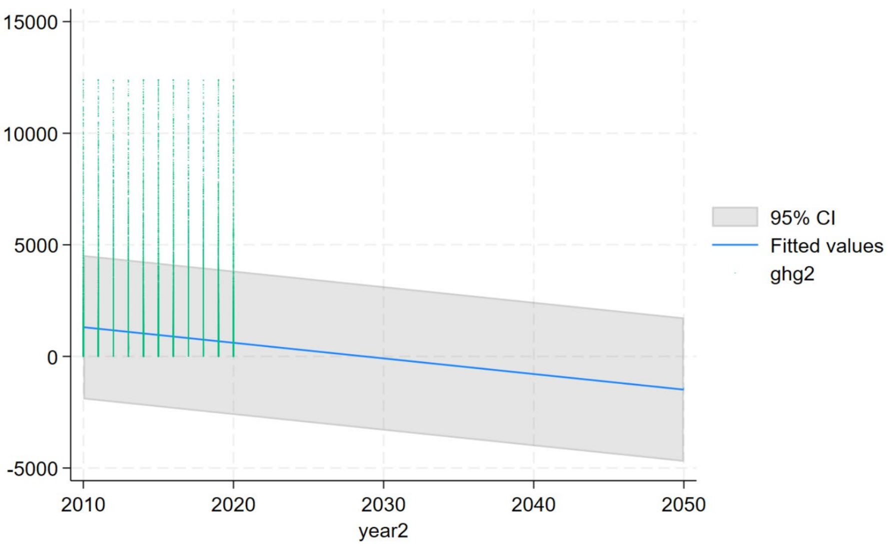

Figure 3. Projection of GHG emissions 2010-2050.

The downward trend of GHG emissions per individual building does appear at first glance to be positive, with a shaded area representing the distribution of 95% of buildings. Yet, in 2050 when buildings are expected to have reduced emissions by 80% there would still be a significant number of non-compliant buildings. This trend is projected from historical data before LL97, which was created in 2019 but only comes into effect in 2024. Accordingly, it is both difficult to predict the impact of LL97 as it has not yet been in effect, and it is difficult to discern whether this trend is reflective of one that will continue under LL97. However, as it stands, a significant number of buildings may not achieve the 2050 goal. This can be seen in the green lines, composed of green dots, representing individual buildings emissions in figure 3. The green dots outside of the shaded area are in the upper 5%, and while less significant in number have as much as twice as many GHG emissions as other buildings just under the 95% threshold.
Another notable feature of LL97 and this data is that it does not consider carbon sequestering and net zero buildings that return to the grid. In effect, it is possible to achieve a negative GHG effect, but this is not considered in the prevue of LL97 or seen in the data of NYC buildings.

Assessment of LL97's impact on building electrification

One of the primary pathways to compliance under LL97 is the electrification of building systems, which includes replacing fossil fuel-based heating and cooling systems with electric heat pumps. This strategy is supported by Building Electrification (BE) credits, which incentivize the adoption of electric systems that are expected to reduce GHG emissions as New York City's grid increasingly relies on renewable energy sources.

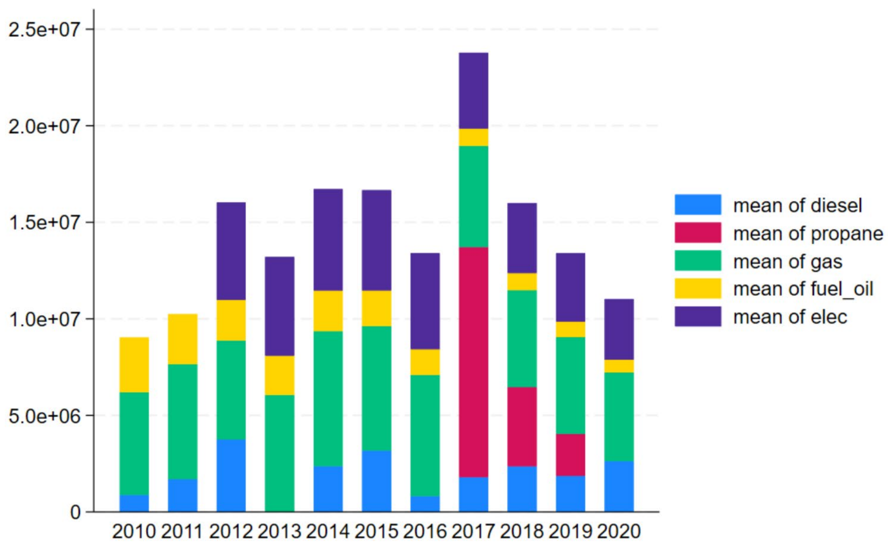

Figure 4. Mean energy sources of NYC buildings.

Taking the mean use across all of NYC's large buildings of different energy types, the distribution is clearly inconsistent. This warrants further research depending on the types of buildings, uses, and so forth. However, the data can show trends in the general use of energy as is seen in figure 5.

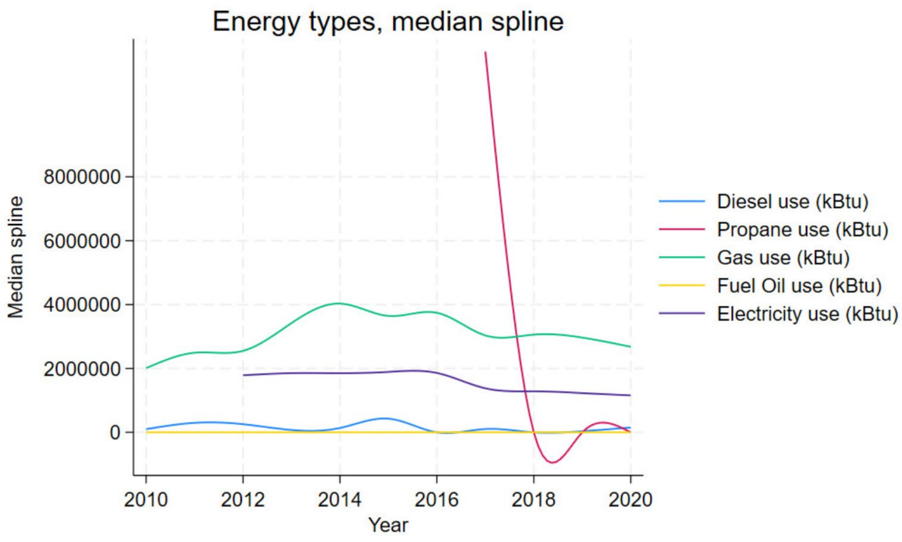

Figure 5. Spline of energy types.

The key changes are the inflection of gas use in 2014, and the steady but decreasing use of electricity which suggests generally lowering consumption. Propane stands out, as it is only used in a handful of buildings. Despite the general but gradual reduction in consumption, there are concerns about the effectiveness of electrification as a sole strategy. Greater consumption of electricity is correlated with increases in GHG emissions in NYC buildings, as can be seen in figure 6. BE credits thus may create a false sense of progress, potentially allowing some buildings to fall short of the overall targets using the BE credits from electrification to maintain or even increase emissions. The reliance on future grid improvements also poses a risk if the transition to renewable energy is slower than anticipated, and the effectiveness of LL97's BE credits is entirely dependent on the renewable transformation of the NYC grid.

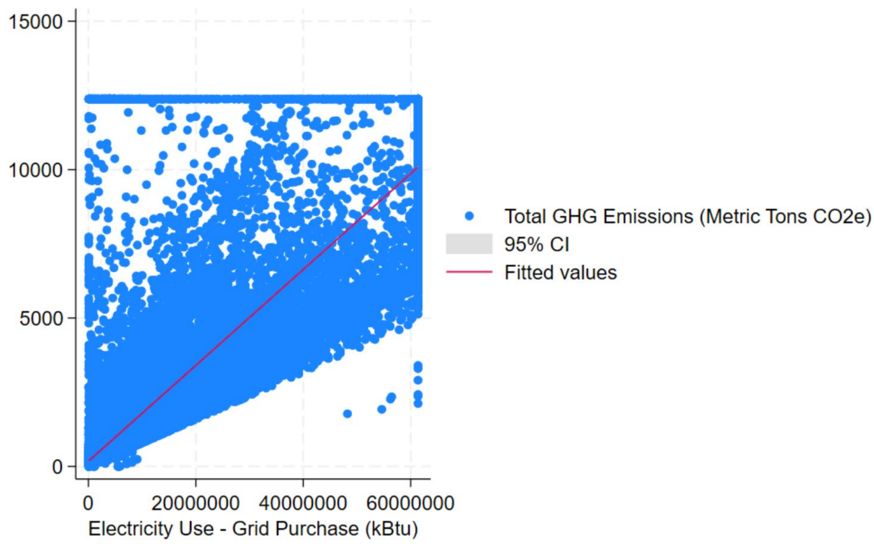

Figure 6. Electricity use and GHG emissions.

Outliers, data and enforcement issues

As a PBR, the success of LL97 is closely linked to the accuracy and reliability of data collected to measure performance, which mandates energy and water usage benchmarking for buildings over 25,000 square feet. This data is crucial for monitoring compliance with LL97 and ensuring that buildings are on track to meet emissions targets.

However, the analysis reveals several challenges with LL84 data. These include inconsistencies in reporting, potential outliers that may skew the data, and a lack of robust enforcement mechanisms to ensure data accuracy. The absence of data quality checks could undermine the effectiveness of LL97, as inaccurate data may lead to incorrect assessments of compliance and progress.

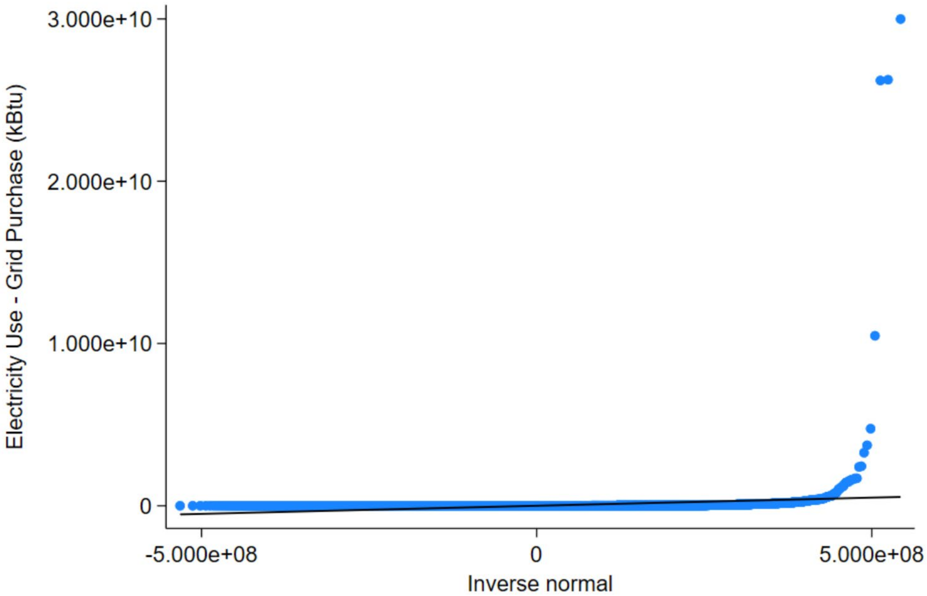

Figure 7. Inverse normal distribution of electricity use.

The enforcement data of LL97 contains significant issues, such as most of the data points seen in figure 7 are concentrated near the origin, suggesting that most buildings within the dataset have modest grid electricity purchases. This clustering indicates a relatively low and consistent level of electricity use for the majority of buildings. However, the presence of extreme values on the far right of the graph, with electricity use far exceeding that of other buildings, reveals the existence of significant outliers. These outliers could represent large commercial or industrial buildings, data centers, or other facilities with high energy demands. The extreme skewness observed in this plot, with a sharp increase in electricity use at the high end, points to an uneven distribution of electricity consumption across buildings. This skewness is particularly important when considering energy efficiency and emissions reduction policies. Buildings that fall into this high consumption category may require targeted interventions, such as energy audits or retrofitting, to reduce their grid dependency and overall energy use. This assumes that there are no errors with the data, and given the scale of the more extreme outliers, enforcement may be neccesary.

Furthermore, the inverse normal transformation applied to the x-axis highlights the extent to which these outliers deviate from the norm. The presence of data points on both sides of the inverse normal scale also suggests that the dataset may contain both extremely low and extremely high values, though the focus here is on the extreme high values. In the case of LL97, the greatest concern is not with the highly visible outliers with high GHG values, but the fact that there are such outliers implies issues with the data collection of

LL84 which may impede enforcement of LL97. The higher the outliers, the easier it is to detect; however, underreporting would be extremely difficult to identify given the volume of the data.

ROLE OF EDUCATIONAL INSTITUTIONS

Educational institutions have the obligation to prepare students for the future. Schools need to provide students with knowledge of the current state of disciplines, their research, and curiosity about new modalities.

To meet demanding PBR goals, innovation is required. There are many lines of research in this field, some of the research conducted includes: carbon sequestering materials, energy and imbedded carbon modeling, and regenerative design.

To create the workforce that can implement existing technologies, training students in Passive House concepts, Standard for the Design of High-Performance Green Buildings [189.1-2020] by ASHRAE Standard, and Leadership in Energy and Environmental Design (LEED) principles need to be integrated into educational curriculums.

DISCUSSION

The analysis of LL84 data (2010-2020) offers important insights into GHG emissions trends in NYC's large buildings. While there is a general downward trend, the distribution of emissions reductions is uneven, with the most significant decreases seen in high-emitting buildings. This suggests LL97's effectiveness in targeting large emitters but raises concerns about its impact on buildings with lower emissions baselines, which may face less pressure to reduce emissions further.

Projections to 2050 indicate that despite the overall decline in emissions, a significant number of buildings may still fall short of LL97's targets. The persistence of outliers with disproportionately high emissions points to challenges in achieving uniform compliance across the building stock. Electrification, a key compliance strategy under LL97, presents risks if the grid's transition to renewable energy is slower than anticipated, potentially leading to increased GHG emissions despite electrification efforts.

Data accuracy and enforcement are critical to LL97's success. Inconsistencies and outliers in LL84 data highlight the challenges of relying on self-reported data, which could undermine compliance assessments. Addressing these data issues is essential for the accurate monitoring of progress.

Educational institutions play a crucial role in supporting LL97's goals by training the workforce in sustainability practices. Integrating green building standards into curricula, as seen at New York City College of Technology, is vital for preparing professionals to meet the demands of an evolving industry.

CONCLUSION

The LL84 data analysis reveals both progress and challenges in NYC's efforts to reduce GHG emissions. While there has been a notable decrease in emissions, disparities among buildings and reliance on grid improvements for electrification pose risks to achieving LL97's targets. Ensuring data accuracy and strong enforcement will be key to the policy's success. The role of educational institutions in preparing a skilled workforce is also critical to meeting these goals. As NYC moves towards its 2050 emissions targets, a coordinated effort across sectors is essential for overcoming these challenges and ensuring sustainable outcomes.

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AN INTEGRATED DECARBONIZATION SPINE FOR THE DIVERSE URBAN UNIVERSITY

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INTRODUCTION

To address the climate warming crisis with the scale of the climate change problem we need to have an educated and scientific response. This paper examines the needed curriculum to develop responses to climate change. It proposes a decarbonization spin made-up of academic modules consisting of learning goals. It evaluates learning goals based on greenhouse gas (GHG) reduction strategies. The curriculum is designed for an urban institution with a mechanism to expand from a single department to a whole college. The decarbonization spine would be implemented throughout classes for specific degree programs.

Scale the Challenge

2024 will likely be the hottest year ever.[1] This record is from the European Union's Copernicus Climate Change Service with data starting from 1940. The scale and impact of climate change is well documented leading to the United Nations Framework Convention on Climate Change (UNFCC).[2] Leading this globe warming is GHG emissions with CO2 being the most prevalent GHG gas.[3]
In 2022, the world saw a growth of 0.9% or 321 million tons in CO2 emissions related to energy, reaching a new record high of over 36.8 billion tons.[4] The built environment generates 40% of annual global CO2 emissions. 13% of the 40% of annual global CO2 emissions was generated by building materials and construction or embedded carbon. 27% of the 40% of annual global CO2 emissions was generated by building operations.[5] Individual cities building operating GHG emissions, which includes CO2 emissions, significantly are higher because of urban building density. GHG emissions are typically composed of 80% CO2.[6] Table1 illustrates the importance of GHG coming from the operation of buildings.

Location	Buildings Emissions	Metric, Sourced	Buildings Emissions Estimated	Metric, Converted	Report Date	Source
World Average	27%	CO2	32%	GHG	2022	7
Houston TX	44%	GHG	35%	CO2	2020	8
Chicago, IL	69%	GHG	55%	CO2	2017	9
Miami, FL	52%	GHG	42%	CO2	2018	10
New York, NY	68%	GHG	54%	CO2	2021	11
San Francisco, CA	44%	GHG	35%	CO2	2020	12

Table 1. cities GHG emissions, as a percentage of their building sector

The rate of self-reported GHG emissions in cities is likely to be underestimated by 18%, this is because of the typical ways in which commercial activity and gas fuel is collected and model. As shown in Table 1, addressing the built environment and buildings offers the most opportunity to reduce GHG emissions in the urban context.

The United Nations Education, Scientific, and Cultural Organization (UNESCO) has developed initiatives and strategies for education to be an essential part of creating sustainable development to address climate change. UNESCO policy is that education is a central strategy to address climate change.

Case Study

New York City is endeavoring to be in the forefront of the United States' decarbonization approach. New York City College of Technology (City Tech) has one of the largest architecture programs in the country. City Tech is ranked as a "Top 15 Public School in the U.S." by U.S. News & World Report.[13] City Tech, with 86% minority enrollment is considered a minority serving institution.[14] Given City Tech's size, position, and student demographic, this program can be leveraged to provide thinkers and professionals to help New York City be in the forefront of decarbonization and empower its diverse student body.

The decarbonization spine envisioned for City Tech is being built out of leading decarbonization instruments. The spine will be implemented to work for the 2-, 4-, and 5-year degree programs. Careful attention to scaffolding for the various degrees and to meet the needs of our diverse students is under development with corresponding specific sequences learning goals and assessment matrixes.

INSTRUMENTS LIST AND EVALUATION

Many organizations and groups have developed sustainable tool kits to create building science guidelines to guide construction of high-performance buildings and structures. The following evaluation systems were analyzed and categorized to determine the areas of focus to develop a matrix of learning objectives for urban curriculums. All the guidelines have some overlapping goals with divergent emphasis.

To evaluate and understand the hierarchy of these evaluation instruments their learning objectives were grouped into subcategories. The taxonomy subgroups used for this analysis are in Table 2.

TAXONOMY GROUPINGS including these elements
Buildings Performance Overview (Introduction)
Including the general concepts and baseline building performance goals
Site and Community
Including building siting, solar exposure and community amenities
Energy Performance and Modelling
Including on site generation, efficiency and energy mode
Building Envelope
Including thermal bridging, fenestration, insulation, and air and moisture barriers
MEP Systems
Including heat recovery ventilators, heating and cooling systems
Water Efficiency
Including site water usage and efficiency
Materials and Embedded Carbon
Including paints, finish requirements and environmental costs

Table 2. categorized taxonomy learning goals subgroups

U.S. Department of Energy Solar Decathlon Building Science Education Series[15]

This is perhaps the most directly transferable to collegiate institutions as the educational series was developed to support students in designing and building a high-performance case study project known as The Solar Decathlon. The Solar Decathlon is a collegiate competition consisting of 10 contests that evaluate various aspects of the buildings, typically including design excellence, smart energy production, market potential, affordability, resilience, and energy and water efficiency. The event is credited with pushing innovation and has inspired thousands of students worldwide to enter the clean energy workforce since its inception in 2002.[16]

The evaluation of the U.S. Department of Energy Solar Decathlon Building Science Education Series (DoE Building Science) revealed its focus on understanding and minimizing energy use in a building. Other areas of concentration include MEP systems and building envelopes.

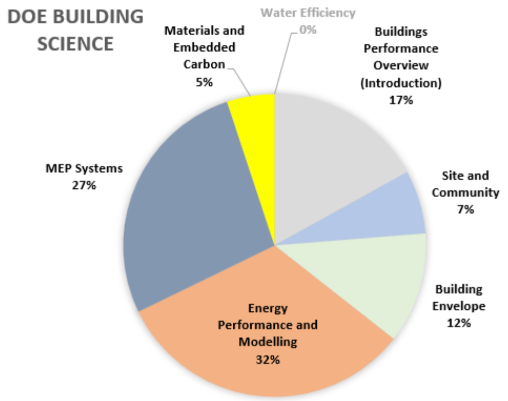

Figure 1. Taxonomy of hierarchy of learning objectives DoE Building Science.

Passive House Certification Training[17]

Passive House certification for a building project is considered one of the most rigorous standards. It is a voluntary certification that is prescriptive and performative. Buildings are required to pass performance tests to receive their certification. Certification requirements include a rigorous development of a build enclosure system which air change cannot exceed 0.6 times a room's volume per hour. The building must meet minimum designated energy consumption to provide space heating, cooling and energy demand while providing year-round comfortable indoor temperatures. Other requirements include heat recovery ventilation, high performance window glazing and doors. Many of these require rigorous architectural design and detailing. Typically, a compact building with good thermal protection is required to achieve this standard.[18]

Many of the requirements for the standard are architectural in nature. This building evaluation instrument aligns itself to a greater extent and then the other analyzed instrument to the field of architecture. Roughly 36% of these training courses involve the billing envelope. Other areas of concentration include MEP systems and Energy efficiency – as illustrated in Figure 2.

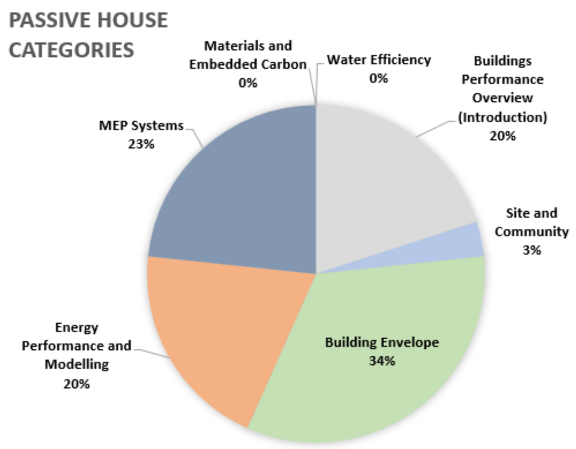

Figure 2. Taxonomy of hierarchy of learning objectives Passive House certification .

LEED v4[19]

Leadership in Energy and Environmental Design, version 4 (LEED v4) is a globally recognized green building certification system developed by the U.S. Green Building Council (USGBC). It provides a framework for creating healthy, highly efficient, and cost-saving green buildings. This is one of the most utilize rating systems in the United States. There are four levels of achievement from certified to platinum. There are currently over 100,000[20] LEED projects worldwide. There are different LEED frameworks for different types of projects, including Cities, Neighborhood Development, Homes, Building Operations and Maintenance, and Interior Design and Construction. [21]

This evaluation utilized the Building Design and Construction (BD+C) framework with the subcategory of "New Construction and Major Renovation". The system emphasizes a holistic approach; this approach tends to emphasize site issues. Other areas of concentration include MEP systems and energy efficiency. This framework system also benchmarks many required areas that are designed to minimize building resource usage – as illustrated in Figure 3. Learning goal categories have been developed from the LEEDs point system.

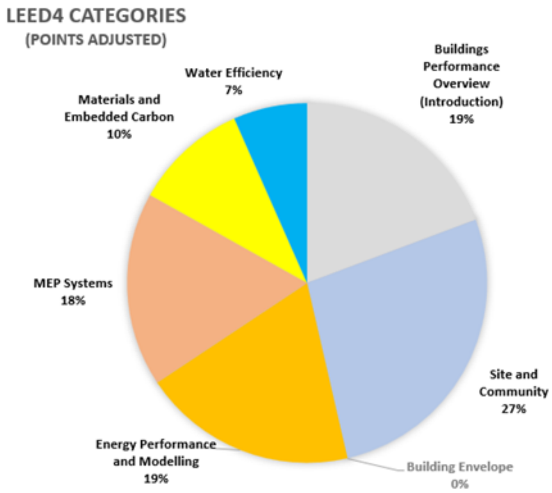

Figure 3. Taxonomy of hierarchy of learning objectives LEED v4.

CALGreen Residential Mandatory Measures 2023[22]

The CALGreen Residential Mandatory Measures was the US first statewide green buildings code. The code became effective in 2009 many of its measures started off as voluntary.[23] The CALGreen Residential Mandatory Measures was developed from the International Green Construction Code (IgCC). IgCC In turn was developed from ASHRAE's Green Building Standard 189.1.[24] This code has the technical rigor that is typical of ASHRAE requirements. ASHRAE was the original acronym for American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE is now utilized as a proper name because the ASHRAE institution has expanded beyond the original purview.

CALGreen evaluation framework is like the Passive House framework in terms of its emphasis on the building envelope. As is typical of many of these systems, the areas of concentration include MEP systems and Energy efficiency. The code is now published by the International Code Council. The International Code Council is the United States largest publisher of codes for states and cities. The code includes stringent U-factor and Air Leakage requirements – as illustrated in Figure 4.

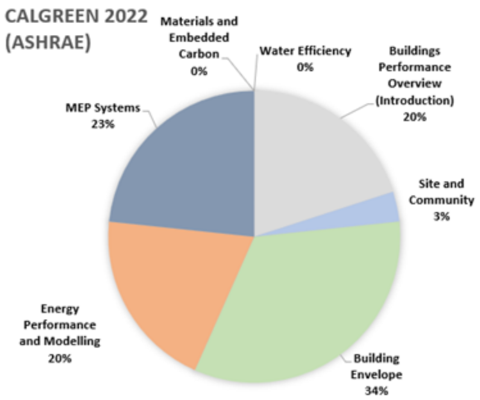

Figure 4. Taxonomy of hierarchy of learning objectives CALGreen.

LEARNING OBJECTIVES

Contributory Instruments

There are many other evaluation instruments that contributed to the development of the learning goals selected. Some of the notable ones include the *United Nations Transforming our world: the 2030 Agenda for Sustainable Development*, which includes 17 goals. *The DOE Zero Energy Ready Home* certification, this instrument has a lot of overlaps with the *DoE Building Science* curriculum. *Building Research Establishment Environmental Assessment Method* (BREEAM) with its origin in the UK has many similarities to LEED learning goals. BREEAM tends to differ from LEED in the way the projects are evaluated.

The Urban Tech Curriculum

There are a lot of crossovers in the topics of the categorized four instruments evaluated. There are clear topics of importance that consist of a baseline of knowledge throughout all the building evaluation instruments. Energy efficiency, modeling, and mechanical systems are consistently key issues for all the valuated instruments. More granular examples include MEP Systems such as water heating and energy monitoring. The largest hierarchy differences can be observed in the instruments evaluated approaches to water efficiency, and site and community – as illustrated in Figure 5.

The four evaluated individual instruments had a low 30 and a high 59 of learning goal topics, for our analysis curriculum learning goals. Using these instruments to add learning goals around weakness and consolidate the redundant concepts, the new proposed Urban Tech Curriculum will have 114 learning goal topics. This categorization and taxonomy approach may not fully reflect the depth level learning intensity of individual topics in relationship to each other. Further work in rationalizing learning goals, weighing difficulty levels is required for the proper scaffolding of the curriculum. This analysis will help us refine ways to strengthen and diversify the current decarbonization spine curriculum which is primarily based on the *U.S. Department of Energy Solar Decathlon Building Science Education Series*. Comparing the distribution of topic areas of the new Urban Tech curriculum and the DoE Building Science, the Urban Tech curriculum as more even distribution of learning goals. The revised curriculum has no focus area over 26%. The DoE Building Science has 32% of its topics devoted to Energy Performance and Modelling. The Urban Tech curriculum has 26% which is the largest in any topic. The comparison between curriculum focuses is illustrated in Figure 6.

This evaluation will give the curriculum team the ability to develop the curriculum in areas needed and weaknesses of the evaluated systems. Using the selected major metrics will provide students with skills and knowledge that are used widely in the industry. All of this will be done in the context of empowering students to reduce the impact of the buildings on the environment and reducing the GHG emissions of the built environment.

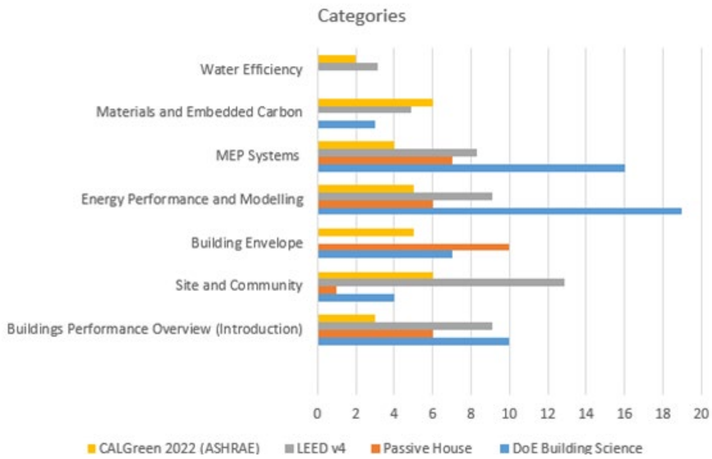

Figure 5. Comparative taxonomy of hierarchy of learning objectives.

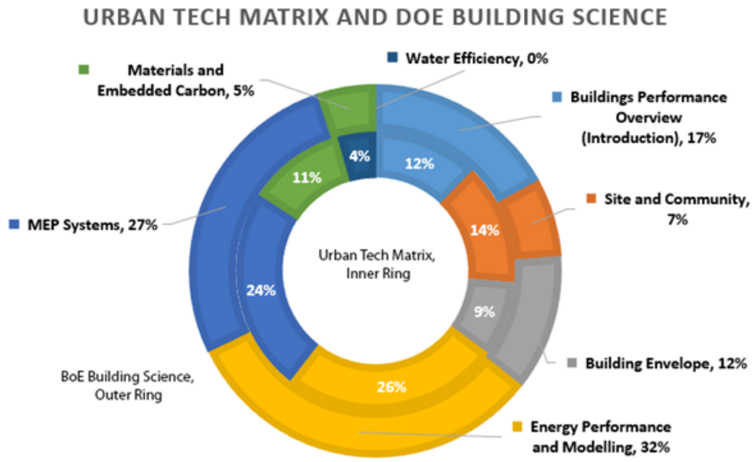

Figure 6. DoE Building Science to urban tech distribution of learning objectives. That ring represents the urban tech objectives while the outer rain represents the DoE Building Science objectives.

Implementation

City Tech is planning to continue to implement the decarbonization spine, it will first be integrated into the Department of Architecture degree programs. The existing DoE Building Science decarbonization spine will be revised to Urban Tech Spine beginning in Spring 2025. In Fall 2025 a new minor in Climate Studies under development will be ready to directly integrate the spine into the program's classes. Climate Studies is being developed in collaboration with departments of Construction Management & Civil Engineering Technology, Economics, Electrical & Telecommunications Engineering Technology, Environmental Control Technology, Chemistry, Social Science, Hospitality Management, Mathematics, Law and Paralegal Studies, and Physics. This collaborative program development will serve as a vehicle to disseminate the decarbonization spin. The goal of the minor Climate Studies degree program is for it to become a new major consisting of a new department. This will provide an opportunity to create a new college within City Tech of Regenerative Design and Technology within City Tech.

CONCLUSION

Urban institutions have unique opportunities to address climate change because of the dense building stock they typically inhabit. They are well placed to teach and research the reduction of GHGs admitted by the built environment. The urban tech decarbonization spine is an example of an instrument that can be leveraged and disseminated across institutions to provide tools to address climate change. The comprehensive nature, including its integration of industry goals, adds strength to this urban tech decarbonization spine.

NOTES

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SECTION THREE

TYPOLOGIES OF COMMUNITY-INFORMED ADAPTIVE REUSE AND WILDING

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INTRODUCTION

This article presents three collaborative design-research projects that investigate potentials of adapting cities to climate and biodiversity challenges in Melbourne's CBD. It employs a typological approach to scope urban adaptive reuse potentials of buildings, spaces and landscapes. Typologies allow finding recurring patterns of space across larger urban territories, that can then be discussed systematically. This approach is used to develop novel approaches to urban spaces that combine densification, greening and urban wilding. Thereby it revisits different concepts of '(re-) wilding' from Europe and Asia and reflects on their transfer to a harsher climatic, post-industrial urban context. This new approach, developed through research-by-design inverts the conventional landscape design process: It starts from found space qualities and typologies, to assess transformation and wilding opportunities. From there, site-responsive typologies for buildings and habitats are derived on which new designs for ecosystem and spatial concepts are based. This process has been strongly supported by site research and community consultation to inform responses to major types of found conditions. Developing urban space and building reuse typologies for different urban situations, the research demonstrates how a typological approach allows to respond to urban situation in a strategic way, mapping out and combining built and natural environments into new urban ecologies. Hereby the article traces a lineage from landscape design to strategic urbanism, including aspects of more than human design, native and spontaneous ecosystems.

SIGNIFICANCE

The study of adapting cities to current challenges of climate change and biodiversity decline has gained prominence in recent years due to the increasing impacts of these urban crises[1] This paper aims to delve into how we can increase resilience, sustainability and livability, and how this can be achieved through transforming existing built environments. The design research examples discussed combine nature-based approaches combining flora but[2] also fauna with retrofitting of building stock and urban spaces,[3] that are mostly looked at separately, as are landscapes and animal ecosystems.[4] This paper combines these intertwined aspects, drawing a lineage between urbanism, architecture and landscape and ecological design. It shows how typological retrofitting strategies used in strategic urbanism can inform urban landscape design. The paper thus creates methodological connections between different design areas, connections that can be exploited in hybrid design and planning approaches.

Their significance in designing cities of the future cannot be overstated, as they would not just have human health and well-being in mind, but also consider our dependence from healthy natural and urban environments.[5] This study builds on three interrelated projects shifting focus from built fabric, public space, to urban ecosystems. 'Cremorne', 'Melbourne Cool Lines', and 'Wilding the Campus', combinedly demonstrate how typological approaches to sustainable urban transformation allow to respond to large sites in strategic ways. The paper concludes with the necessity of hybrid responses in to respond across the three domains of urban landscape, urbanism and architecture to particular sites.

PROCESSES OF ADAPTING EXISTING CITIES

The process of sustainably adapting existing cities to the current challenges of climate and biodiversity requires multifaceted approaches due to the complexity and variety of existing urban environments. Comprising buildings, open spaces, green areas and waterways as well as existing uses and users, unique characteristics and needs of different urban areas need to be well-considered. In the described design-research suite, we examined for each design context, existing buildings, spaces, and communities, but also climatic, topographic, ground conditions and proximity to water. These are key to develop strategies for sustainable adaptation targeted towards their needs. Thereby urban retrofitting was chosen as the obvious carbon-neutral approach.[6]

A crucial site-specific approach started with conducting extensive site visits, interviews and observation of how people used spaces together with extensive studies of historical maps to understand manmade changes to landscapes. This data was used to create comprehensive maps, detailing aspects of vegetation, ground conditions, topography and water elements or accessibility, existing programs and needs. In addition, understanding the city's climate, wind patterns, shade, and exposure to various elements provided valuable insights into how to better adapt the city to its environment: identifying dormant opportunities and obstacles to be overcome through precise networked interventions.

Identifying needs, opportunities, and constraints aided determining the types of interventions needed, and the areas and situations where to effectively implement those. The studies were conceived around a method comprising a series of typical interventions that strategically connect. This approach has been a powerful tool in proposing large-scale schemes for adapting cities, that start from mapping out existing potential and needs to discuss most effective intervention types. Such strategic interventions may expand existing pedestrian spaces within the city and reconnect gaps that may exist in those connective urban tissues. The method enables a systematic approach to city adaptation, and progressive implementation of strategies, intervention by intervention. This ensures that changes can be made gradually and effectively.

The strategic mappings created at the start and end of the studies have served as both an initiating point for identifying strategies and ideal intervention areas, as well as tool of synthesis, structuring proposed strategies. Maps, as a key tool in the method, provide a clear overview of proposals of the current state of the city, enable the tracking of progress for the discussion of final outcomes. Mappings were further effective at creating comprehensive and comparative views of the different interventions. In the discussed projects, maps were combined with keys of interventions. Represented as icons, the representations triggered reflections on commonalities and differences between interventions, while structuring propositions around common narratives. Each map’s critical reflection informed the next study’s objectives, expanding previous investigations into an overarching thread.

FIRST EXAMPLE: FOCUS ON BUILT FABRIC AND COMMUNITY

The first study *Building Mixity!*[7] aimed at the sustainable transformation of a then relatively preserved post-industrial Melbournian area, Cremorne. We focused on its uniquely diverse built fabric, history, and community, as the area had hosted factories, workers housing, shops and pubs creating a unique mix of industrial types. It was still with street life and a deep sense of community. This led us to develop the university research through extensive community consultation, reflecting the importance of involving residents and professionals. Two primary concerns emerged: gentrification and affordability and the changes these factors bring to the community. Additionally, the increasing car traffic and parking problems from newcomers posed significant challenges.

Figure 1. Vision of Cremorne with color coded transformation types. Extract from Building Mixity!

In response to these concerns, the project identified a series of cases, and proposed a 'mixity[8]' of adaptive reuse types for building. These transformation strategies were developed to cater to different existing building types. They aimed to reduce emissions normally generated by demolition and rebuilding while adding density to address both growth pressures. Their reduced carbon and land footprint of high-density construction, as can be seen in the aerial view (fig.1) would further reduce relative land cost of spaces. Meanwhile those strategies aimed at maintaining the fine grain, character and identity of Cremorne.

The proposed transformation typologies involved a detailed examination of the existing buildings. This area had so far been under-researched from an urban and architectural point of view, despite its rich history as an industrial working-class context.[9] Despite its unique diversity it comprised many types also found in post-industrial areas across Melbourne, currently flagged for redevelopment. This made it even more relevant to research, while being overlooked by conservation authorities despite being key urban transformation areas. Finding heritage- and carbon-conscious reuse strategies was urgent.

One objective was to build on and expand the diversity of spaces, building types, and uses (fig.1), as outlined in the book *Building Mixity!* The added spaces through transformation would expand the mix of unit spaces catering for various users and uses. This approach to land efficiency and reduced living footprint would also maintain a sense of place through building stock reuse. Published to great acclaim of community and profession, the study was shortlisted at the Australian Urban Design Awards. Our 'mixity' concept combined with different affordability models further addressed the first community concern of gentrification and affordability.

The creation of a typology of building types[10] and densification strategies enabled a systematic approach to the adaptive reuse. Iconic working-class types were communicated with a color-coded diagrams connected to a strategic map- readable for lay as well as professionals. This map introduced another sustainable aspect: The project proposed to link interventions by a green network, serving as the connecting tissue for the built fabric (fig.2). Creating walkable routes, the sustainable green network addressed car use, introducing a slowed one-way traffic concept. It connected with public transport and car parking at the edge of the precinct and ecological corridors of riverfront and parks through topographical treatment and green bridges. However, the landscape was only sketched out as overarching concept, indicating that further work was needed.

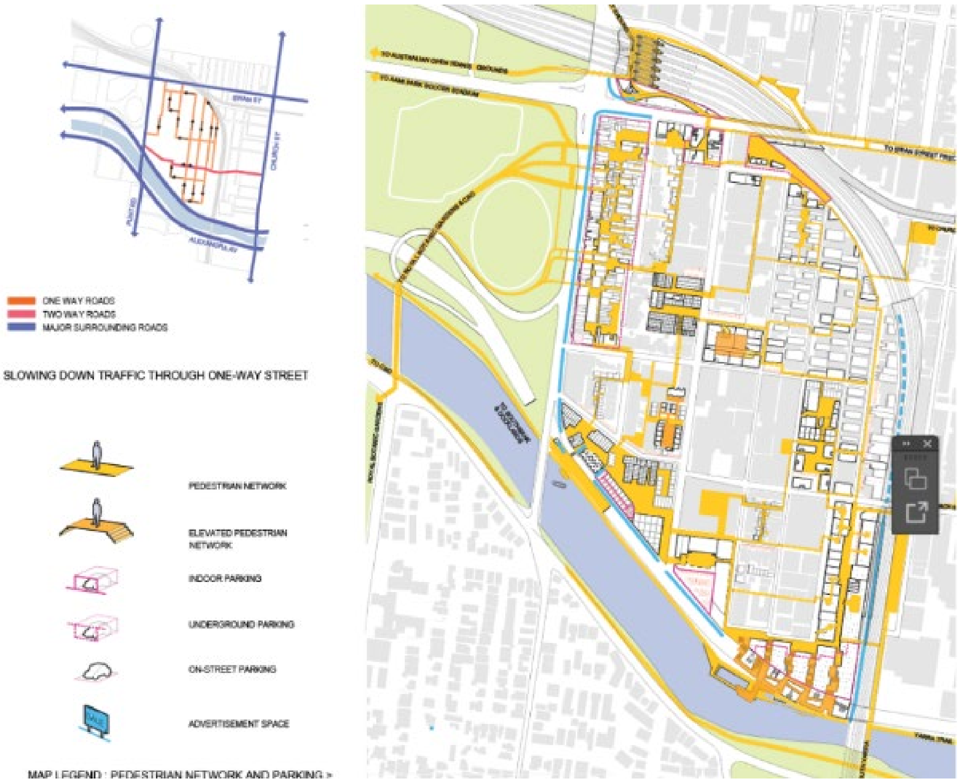

Figure 2. Pedestrian network, traffic and car concept, traffic and parking concept. Extract from Building Mixity! book.

SECOND EXAMPLE 'MELBOURNE COOL LINES': FOCUS ON PUBLIC SPACE

The *Melbourne Cool Lines* research-by-design investigated, how such a green network could function as an urban landscape, examining the interfaces between landscape and the urban/architectural realm. This project followed a a transdisciplinary approach to climate change, heat, and flooding within the city. Collaboration with scientists, water engineers and ecologists from the Collaborative Research Centre for Water Sensitive Cities supported the project built on water-sensitive urban design and climate design strategies using nature-based solutions to improve climatic conditions through water retention, shading and evaporative cooling.[11]The project operated in post-industrial North-West Melbourne. This meant identifying spaces within the existing city where blue-green spaces could be implemented to contribute climate resilience. Again community interaction and site research informed the choices of spaces we focused on for reuse and the identification of their needs and challenges.

An adaptive-reuse approach was this time applied to underused spaces (fig. 3). Different open space types were identified. Some consisted of areas under bridges and highways (1), remaining land adjacent to infrastructure (2). Some opportunities were found in traffic islands in-between parks (3) or disused buildings surrounded by parking (4). Design responses incorporated parklands with pavilions (1), terraced green walls (2), linear parks (3) and porous building-park interfaces (4), creating a diverse and multifunctional public space network.

Figure 3. Melbourne Cool Lines interventions 1-4.

The blueprint proposal entailed different types of urban reuse. Integrating architectural, infrastructural, and ecosystem elements within optimistic urban landscapes. These blended urbanity and nature, mixing buildings, people, vegetation, and water in ecosystems that mixed built and natural environments. This synergetic vision for the city (fig. 4), showed that ecosystems and built environments can coexist. An animated overall plan[12] presented the series of proposals as a network of interventions that extended existing green areas into a coherent pedestrian scheme, connecting to bike and public transport. It expanded the Cremorne Network idea, doubling its functions as drainage and ventilation network and ecological corridors for flora and fauna.

Figure 4. Melbourne Cool Lines Network map, as comic for community engagement.

Presented through visual impressions of evolving, untamed ecosystems, it suggested the temporality of seasons and weather. The notion of such blended worlds where city, people, nature and animals coexist and meet is still emergent, as is the idea of wild native ecosystems within cities, facilitating unexpected encounters. These ideas would be further developed in the third study, in consultation with the community.

THIRD EXAMPLE 'WILDING THE CAMPUS': FOCUS ON WILD NATIVE ECOSYSTEMS

Wilding the Campus[13]' investigation delved into how to implement urban ecosystems, focussing on spontaneously developing native ecosystems, creating different types of urban ecologies that use nature's embedded capacity to adapt to location and change. Addressing the decline in biodiversity by supporting flora and fauna, it promoted sustainable, diverse urban ecosystems. This contrasts with conventional planting often operating with limited (mostly tree) species, and mostly overlooking animal ecosystem aspects. Such myopic planting often remains unsuccessful as single species do not thrive in isolation. How could a more wholistic vision of landscapes and interspecies dependence promote more resilient and adaptable urban ecology? How could such ecosystems be designed as reuse strategy for urban spaces?

This happened as a movement of wilding was taking traction overseas. 'les friches' projects[14] in Paris revived old factory sites with cultural and wild revegetation strategies as in la Recyclerie in St Ouen. The city was further experimenting with native flowers in parks and gardens of the Jardin des Plantes e.g. Berlin followed a similar path experimenting with ruderal landscapes along former train tracks,[15] questioning the notion of weeds, maintenance, grass-mowing and curation. In Singapore, Saladdressing re-introduced native jungle as park into the city, transplanting square forests,[16] sometimes with some animals in the trees. How could this function in a Melbournian context with its extreme temperatures?

Our last investigation, in an adjacent area to the previous study, started with detailed research to identify found space types, and community workshops to identify needs and desires.[17] This led to a framing of ecosystems around animals, which the community positively reacted to. Calm uses for lunch, meetings, reading, relaxing and animal observation resonated in this postindustrial university area. The site revealed different spatial conditions, including sloped (1) , narrow-shaded (2) and areas disconnected though traffic (3) and built fabric (4) demanding appropriate landscape design responses. The project proposed topographic (1), vertical (2), bridging(3), and tunelling (3) as a solution.

A focus on native ecosystems and landscape types, and associated animal species formed a new angle to respond to different conditions: Sloped sites would create rain catchments with billabong-ponds for aquatic species (1). Narrow lanes host climbing plants for insects and lizards (2). Green bridges (3) and tunnels (4) extend tree canopies across urban speedways for possums(3) and bats(4). These typological answers were captured in an overall plan strategizing site responses.

Figure 6. Ecology types: topographic wetland, vegetated bridge, alleyway vines, green passages

The project questioned the role of animals for landscape architecture and urban planning. Often overlooked, the project reconsiders their role in design and planning processes. Animals have become a way of framing intervention as habitat types, diagrammatically presented in an overall proposal map. This responds to the connection the community showed with ideas of animals in the city, and ecosystems as backdrop for calm activities. Four habitat types were tested as prototypes and exhibited alongside the urban strategy in an exhibition to the community.
The project transferred the typology-approach to ecosystems, distinguishing site conditions and responses. This provided a systematic approach to implementing urban ecosystems responding to found spaces. A color-coded strategic map locates proposed interventions. This strategic map represents transfer strategic urbanism approaches from the *Building Mixity*! strategy, to landscape in *Wilding the Campus*. Aligning with methods from urban planning for recommendation and building codes, it provides a practical tool for implementing such urban interventions.

Figure 7. strategic map showing "Wilding the Campus" wilding typologies.

CONCLUSION

Hybrid responses in urban planning, design and development are becoming increasingly necessary, particularly in contexts spanning built, urban and landscaped spaces. The presented projects have offered complementary responses to questions about how to adapt cities. Our experience in architecture, urban and landscape design enabled us to connect strategies between these domains, using typological and strategic thinking from urbanism[18] to apply it across architecture, urban and landscape design, where such approaches are uncommon. The thinking across projects has further enabled complementary investigations across domains connecting architectural and landscape strategies.
A key strategy in these projects has been the typologisation of conditions and design responses, where exemplary situations are extracted to test best approaches, discuss findings and apply them with variation across similar sites. This approach enables a systematic, efficient investigation of novel terrains to develop transferable ideas. It facilitates strategic approaches to large sites with different types of conditions, diversifying solutions as it recognizes that not all conditions are the same, thus encouraging diversity of responses.
This is novel, as in Water Sensitive Urban Design and Climate Design, solutions tend to be presented as universal, with differences in context and climate often being overlooked. But no ecosystem design

solution suits all. Further, while typologies classify design approaches, they also recognize that each approach can be detailed and played out in myriad, acting as a further driver for diversity. Site-specific retrofitting strategies lead to design-responses that are driven less by program and more by site particularities. Schittich[19] suggests that existing conditions often drive more interesting solutions than greenfield. This is particularly evident in our examples where unexpected configurations, geometries, topography, and climatic conditions lead to innovative and unexpected responses.

Strategic mapping has enabled strategizing areas where similar cases and responses could apply. This allows for local testing of transferrable approaches, which can be applied elsewhere. It further enables a gradual deployment of climate strategies across sites, that can be progressively phased and rolled out with staggered funding. Decentral approaches further benefit local solutions, which can be progressively connected. Such time sensitive deployment enables local testing to inform later expansions. Temporary interventions and prototypes, as in our latest case, can be used to test community responses to improve the details of strategies before implementing permanent designs. This facilitates learning from one intervention and project phase to the next.

Learning from the COVID-19 has informed such strategic urbanism approaches. During the pandemic, the parklet movement took off in Melbourne, first with localized temporary parklets. Online maps surveyed these parklets,[20] expanding the movement. Councils started emulating the first initiatives. Growing networks of parklets along high streets emerged. Some of these have permanently shaped post-covid Melbourne. Similarly, climate and biodiversity adaptation could start from discrete areas, with temporary interventions spreading, following a networked approach. This would enable progressive financing and flexibility to react to external factors such as the changeable economy and community response. Here our latest example (fig.7.), which has just morphed from temporary prototype to a final permanent revegetation strategy of a parking is one example of a case in point.

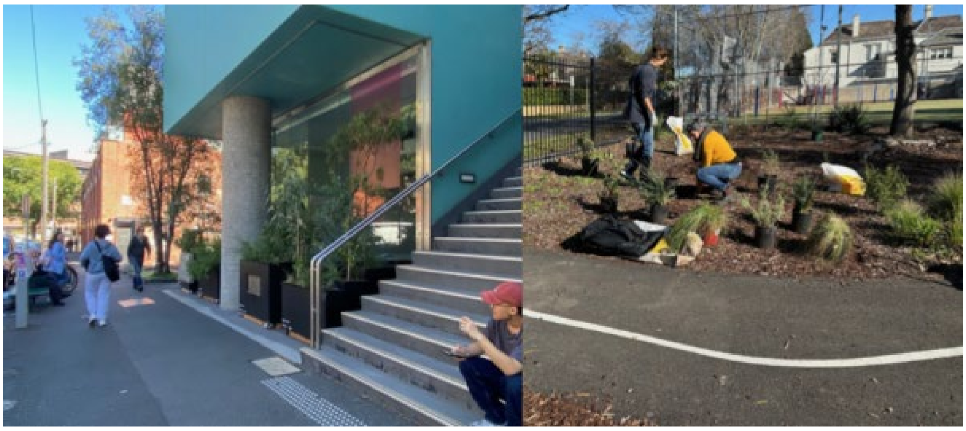

Figure 7. Photos of four temporary ecosystem incubators in Melbourne CBD in front of wild streets exhibition space, and process of relocation to permanent grounds next to a public school.

NOTES

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GENEROUS CITIES: COMMONS-BASED HANDLING OF EXCESS MATERIALS

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INTRODUCTION: EXCESS

A common way to describe the contemporary globalised world is that it is organised chiefly around industrial production. That point of view, although insufficient to provide a deep understanding of the many economic, political and social dynamics at play, is prevalent in the public opinion. The mere fact that it has uncritical wide adoption by the media and the general public has many consequences. Crucially, it makes it all but inevitable to accept that the global economy depends on an increasing extraction of raw materials, their transformation into products, and the distribution of such products to consumers. Contemporary industrial production is, after all, usually structured in such a way that multiple materials are extracted from nature – often in parts of the world distant from one another – and transformed into products through the use of labour, energy and applied knowledge.

That mode of organisation impacts the entire supply chain, but its final section is particularly problematic. It would make sense to assume that the products of industrial production would better stay in use for as long as possible, lest the investment – labour, energy, and knowledge – disappear altogether when products are discarded, or at best recycled. In other words, the resources invested into manufacturing are literally wasted at the end of the product life cycle. The so-called linear mode of industrial production[1] generates increasing volumes of objects that can not be reincorporated into production processes. Such excess materials are largely wasted, despite often still being potentially valuable. Recent policies attempting to increase the rate of recyclable materials' collection address this situation partly, but they cause other sorts of undesirable effects, as will be discussed in this thesis.

Another implication of describing society solely in terms of industrial production is the promotion of a worldview – and consequentially a culture – based on commercialisation and competition, which lacks a holistic perspective of the social and environmental impacts of economic activity, and in particular its negative externalities. Alternatives to address the impacts of industrial production have taken the shape of systemic approaches such as cradle-to-cradle (C2C),[2] circular economy,[3] and doughnut economy.[4] All those takes offer a well-structured narrative and recommendations about production and consumption, material lifecycles and economic systems. There are however contradictions in how – or if – those frameworks sufficiently address cultural and symbolic aspects of waste and attempt to find concrete solutions under that perspective.

Relying exclusively on market-based mechanisms limits the potential transformative effects of such proposals. Profit-oriented corporations have historically been incentivised to adopt questionable practices to increase their margins. And that happens not only regarding source materials. Whenever possible in legal terms and acceptable by public opinion – or invisible from it —, such organisations will:

- Increase prices as much as possible, occasionally making use of sophisticated techniques to manipulate consumers' perception in terms of style and identity. That allows them to make their products be seen as more valuable than the competitors' – even in the cases where they are objectively the same.
- Reduce wages and working conditions to the bare minimum established by legal or class-based workers' rights regulations, often relocating their industrial plants to parts of the world where labour is cheaper, or less protected.
- Employ materials from unethical provenance – sometimes relying on child labour, environmentally questionable extraction and processing of materials, poor workers' protections, or even sourcing materials from conflict and war-thorn areas, as well as engaging with corrupt actors.
- Ignore the long-term impacts of their products once they are not in use any more – sometimes actively promoting planned obsolescence and/or concealing known information about the low repairability or the high toxicity of their products.[5]

I argue that society can truthfully seek novel and holistic ways to address the impacts of excess materials, but profit-oriented corporations should not be the only actors involved. A coalition of stakeholders representative of the many forces at play must be forged. Unfortunately, we must accept that waste production is inevitable for the foreseeable future.

My doctoral investigation centred on how localities can cope with excess materials under a conceptual framing of reuse – through repairs, upcycling, or re-circulation. This specific research focus was based on two elements. The first, my hands-on involvement in the past with community initiatives promoting the reuse of materials. I build on experiences reusing discarded electronic equipment in the MetaReciclagem network – active in Brazil between 2003 and 2012. The second factor in deciding on this particular research topic is the scarce literature I found connecting inclusive urbanism, digital equality and environmental issues. Particularly in discussions about smart cities, there seems to be no awareness of the rich scholarship, for instance, on Lefebvre's concept of *Right to the City*[6] and its implications in how policy is designed and implemented. Equally absent are approaches to handling waste in urban contexts that go beyond logistics and discuss impact and benefits to local communities and society.

WASTE AND CITIES

The entirety of my research journey, from arriving in the UK in 2019 to the moment I finished reviewing my thesis in Berlin in 2024, followed an explicit goal. That is, going beyond merely deploying technologies, rather discussing how to pursue a better future for cities and their populations. My thematic choice for that investigation was to focus on local systems to promote the reuse of excess materials – broken, unfit, unused, discarded objects – in contemporary cities and regions.

Regarding cities, discussion about the reuse of materials is often affiliated with the field of waste management. There are, however, problematic points in such a thematic association. The first question is the extent to which public understanding of waste has gradually been reduced to the attempt only to increase the volume of recyclable materials collected and processed by municipal services. The dominance of a top-down view of recycling as the end goal of waste management leads to distortions that must be addressed. The second problematic point, perhaps of a more conceptual nature, is that accepting to define things out of use as waste conditions society's perception and expectations about such materials. To that point, not even the well-known formulation 'waste is matter out of place' is sufficient. The theme ought to be challenged from a perspective that considers power dynamics and conformity to a consumerist society.

In my research, I adopt an alternative take: addressing excess materials in cities and regions through collaborative practices of reuse. In so doing, I shift the focus: from an increasingly automated collection of materials that should disappear from the public eye as soon as possible, to an ongoing effort to identify and expose the potential value of discarded materials, and actualise that value with (and to the benefit of) local agents.

Instead of top-down waste management, the focus of my work can thus be better framed as creating systems for commons-based waste prevention. That is the perspective I apply to my experiments with digital technologies and modes of organising. I depart from the incremental improvement often seen in smart city initiatives: instead of deploying sensors and data collection tools to improve objective control by entities of centralised power, my research experiments with the opposite: the collective generation and governance of data to rebalance power relations.[8] I sustain that any solutions – technological or otherwise – in that context should be co-designed with knowledgeable stakeholders to ensure that relevance, trust, privacy and long-term dependability are incorporated by default. A chief concern is to ensure that those social groups already involved in reusing materials are not marginalised by future developments.[9] Instead, I want to leverage the capacity of such groups – small businesses, community initiatives or individuals – by exploring what would be a labour point of view[10] in the reuse of materials. It may be obvious nowadays, but it is always important to make it explicit: recycling is not the only solution for solid urban waste. In fact, there are many cases where recycling is unsustainable, too impactful or downright impractical.[11] Recycling has acquired a positive cultural value over the last decades, embodying a growing concern for the future of the planet. But objectively, it is an industrial process whose goal is to collect materials that are not in use, and transform them back as much as possible into raw materials that will feed other industrial processes.[12] There are accounts depicting the public acceptance of recycling as being engineered precisely to distract attention from the ill effects of the industrial use of plastics.[13] The requirements for that system to work properly are very high. First, there must be a steady influx of recyclable materials, preferably already cleaned and sorted according to type and quality. There must be an industrial plant with the proper equipment, methodologies, workforce, sources of energy, social responsibility measures, and environmental licences. Finally, there must be an active market willing to buy recycled materials.

Influx, processing, output. Even taken in broad terms, there are many weak points in that design.[14] When one tries to consider other aspects, this fractal setting gains even more complexity. For instance, the logistical challenges to collecting recyclables and redistributing recycled materials are already high, even if one does not factor in the cost and environmental impact of transporting things within the city – from neighbourhoods to sorting facilities, to recycling plants, then on to retail and finally to manufacturers willing to use the recycled materials for their production. Furthermore, even that image is based on the reality of a contemporary western/northern city with ideal transportation means, a population aware of the benefits of properly sorting recyclables, and an industrial sector in need of materials. Most cities and urban areas in the world can not be portrayed that way, which complicates the situation even more.

My take is obviously not to altogether replace waste management and recycling with reuse. Those practices need to handle the greater part of waste, today and in the foreseeable future. My research, however, aims at reshaping the imagination about excess to promote community-based reuse of materials alongside conventional waste management structures.

DESINING POST-CONSUMPTION FLOWS

It is disheartening to realise that despite a recent increase in public awareness to issues of sustainability and climate change, the imagination around product design is still very much focused only on everything that happens before a product is purchased. Granted, there have been important changes over the recent decades, as users increasingly moved centre stage of the design process, which brought real-world use scenarios to the fore. There are also excellent alternatives currently under development that offer more sustainable sourcing of raw materials. However, there is little thought about what happens once the products start to fail, or are kept unused for any other reason. Of course, manufacturers are increasingly pressured by the public and policymakers to enable easier repairability and recyclability of their products, as proposed by the *Right to Repair* movement.[15]

Nevertheless, at any given second, virtually every city and town in the world is discarding high volumes of materials. A considerable part of those materials should not need to end up in recycling or incineration, or piled in landfills. Potential value is literally being wasted everywhere. The solution for that is not merely logistical. There are political issues to be unveiled, as well as cultural ones. Waste has deep connections with inequality.[16] My thesis aims to significantly contribute to that discussion, starting with a reconnection of goods and products with the local and regional contexts in which they are used. The first time I read about 'bioregions' was in the writings of John Thackara.[17] It is a perspective that asks one to think in a systemic way that integrates city, rural areas and nature. It provides a powerful way to expose assumptions often kept under the radar, especially to acknowledge externalities. Even though the themes around repair, reuse and waste are not related to a rural or a natural setting in obvious ways, it is still useful to think on a scale wider than only the city to understand how matter flows and is transformed within it.

Bruno Latour[18] uses the image of 'black boxes' to describe mechanisms whose internal functionality is opaque within a system. Such conceptual objects are only expected to receive inputs and, from them, provide outputs efficiently. One may argue that opening up black boxes and making them transparent reduces the overall performance of the system. On the other hand, it is only possible to have a clear picture once we look into the black boxes, expose the assumptions they are based in, and include more people in defining how they operate. The usual depiction of waste management systems is full of black boxes. My research tries to intentionally open up some of them.

BEYOND CIRCULARITY

The vision of a circular economy is central to any contemporary discussion about waste and reuse. Nonetheless, my research is not completely aligned with that perspective. One of the many interesting questions I was asked shortly after moving to Dundee came from Professor Jon Rogers, Principal Investigator of the OpenDoTT programme. How about, he asked me, you thought of shapes other than a circle? Once I let that sink in, I began to understand what my main problem with the circular economy was. We can, inspired by the cradle-to-cradle concept,[19] accept that 'waste equals food', or in other words, that the residues of industrial production could be seen as nutrients that can be fed back to the system. The second step would then be creating ways to ensure that the nutrients are efficiently identified, sorted, cleaned and transformed back into food. It is, however, important to ask what sort of creature we are feeding with those nutrients. In other words, should a more circular economy be used to provide frictionless nutrient flows to an industrial sector that has proved time and again that its only goal is to reproduce itself infinitely with no respect for nature and humankind?

My take differs in shape, if not in substance. Instead of nutrients, I like to think of discarded materials as potential value, or potential wealth. In 2016, I spent some weeks in Nantes, France. I was there invited by a local arts organisation to explore the scenario of circular economy projects in the region. The most valuable thing I learnt then was about the *agents valoristes*, in the original. It is an actual professional role: the person whose job is to evaluate what parts of discarded or donated materials can be either sold, repaired, or transformed. It reminded me of those TV shows of antique traders going to small towns to find potential acquisitions for their businesses. There is situated knowledge, skills and sensibility in that to be understood and put to use. The image of the *valoriste* was a constant inspiration for my research.

One of my favourite authors of near-future fiction is Cory Doctorow. I often say that most people read the wrong *Makers* book. Unlike Chris Anderson's title that focuses on a 'new industrial revolution',[20] the one written by Doctorow[21] is a story of a group of creative engineers in a warehouse in Florida repurposing the excesses of industrial production. One of them says: 'the world is full of capacious, capable, disposable junk and it cries out to be used again'. A good *valoriste* can likewise see beyond the intrinsic characteristics of things, and envision how they can be dynamically reconfigured in different situations. For instance, an unrepairable object considered worthless for its original use could become valuable for an artist looking for particular material characteristics for an artwork.

If society is to cope with the vast amounts of waste being generated every day, the skills of the *valoristes* should be recognised and disseminated. Once that happens, we may see flows of matter not necessarily returning circularly to further fuel the industrial sector, but instead being absorbed and generating social value within cities and community centres, workshops, social enterprises and nonprofits. By treating waste as potential wealth, it is possible to design abundant systems that fight social and economic inequalities by combining the skills and labour of *valoristes*, repair and crafts professionals, amateur upcyclers and other groups active in the reuse of materials.

These initiatives can collect materials from their surroundings, identify the potential value in them, and make sure that that value is reverted to people and organisations in the vicinity. They can occasionally exchange materials with other initiatives in the neighbourhood or beyond it. Only afterwards the materials are to be sent back to the final disposal – recycling first, incineration or landfill when there is no alternative. Taken as a whole, such a system would hardly take the shape of a circle.

My PhD research focused on designing alternative approaches to excess materials. I have entertained the idea of creating technological solutions – sensors, equipment, online resources – to help identify and sort reusable materials, allowing more people to become networked *valoristes*, so to speak. I thought of using blockchain and online ledgers to track the lifecycle of particular objects, as some projects are already doing. I envisioned a future where I would get together with people developing apps for waste pickers in developing countries and see how my research could help. Or to develop concepts for city-based (or, better yet, bioregional) centres for the transformation of idle materials. I wanted to find ways to escape the seldom-challenged idea that only local governments and privately owned corporations should be in charge of all the processes related to waste in cities. What other ways could local societies propose to make good use of those potentially valuable materials?

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RESTORATIVE RESIDENTIAL BUILDING TRANSFORMATION FOR SUSTAINABLE CIRCULAR SOCIETY

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INTRODUCTION

37% of global carbon emissions is from buildings (BEIS 2019): as such designing to restore and refit buildings for transition towards net zero is critical to livable cities. The Business, Energy and Industrial Strategy Committee report (BEIS 2019) from the house of commons (UK) on "Energy efficiency: building towards net zero", informed that the current rate of building restoration in the UK needs to increase on average by 7 times to meet net zero 2030 targets.

This study presents a case on a restorative residential building project consisting of 100 apartments in the city of London. The objective of the project is to transition towards net-zero and provide valuable insights for similar regional and local initiatives to reduce barriers and accelerate transformation in creating livable buildings and cities. Adopting a whole systems approach based on circular economy (CE) 'R' strategies,[1] the project is guided by 12 design considerations across meta, social, economic, and natural-environmental categories. The overarching goals are to foster sustainable circular transformation, promote societal well-being, and restore the quality of the natural environment. In the past this has rarely been the case[2] as CE projects are generally orientated towards a technocratic approach.[3] Although, these projects are frequently met by barriers and even abandonment.[4] Inclusion of social and economic design considerations are expected to advance CE [5] and strengthen a systems transformation.[6] Although, in general CE projects lack consideration of interrelationships with social and economic models[7] including built environment.[8] This represents a gap in research which this study aims to investigate to understand the contribution of integrated social and economic design considerations for systems transformation in a CE built environment.

Given the urgent challenges of extreme climate change risks[9] and geo-regional resource (energy, water for example) supply uncertainty,[10] this study implements a transformative intervention through building restoration with intention to contribute to "teach climate action to run".[11] The aim is to reduce resource usage, waste generation, and pollution with the promotion of people's wellbeing. Project values are set to improve both technical and social dimensions.[12] The project engages a diverse group of transdisciplinary stakeholders, as described by Stock and Burton,[13] including policy advisors, architectural and planning experts, leaseholders, building management, local enterprises, academics, and designers for long term change.[14] Data on stakeholder interrelationships, socio-technical- economic aspects, are observed through multi-stakeholder meetings over a longitudinal 18 month and continuing period. The project underscores the importance of co-designing interventions with the involvement of diverse actors while guided by 12 design considerations. This whole systems sustainable circular approach helps overcome barriers, foster desirability, and expedite transformation within the context of a circular economy through abductive reasoning[15] between the real world challenges and the twelve design considerations. The findings highlight the significance of including social and economic design considerations to advance built environment CE transformation and accelerate net zero transformation as they can a) broaden reach of the transformation; b) unfurl an increased number of socio-technical barriers which can be addressed with codesigned services to aid advancement of CE and c) distinguish preferred decision making aspects for quality service providers to attain goals.

Time has run out

Humanity has been aware of our impacts on the natural environment as because of our ways and being and doing, since the 1960 -70's with the release of groundbreaking studies as presented in Rachel Carson's silent spring (1962)[16] and Meadows et al., The Limits of Growth (2005),[17] for example. Over time there have been many reports and conferences perhaps the most cited and discussed the Brundtland report.[18] Nevertheless, while the U.N.[19] provided guidelines for sustainable development and increasingly makes explicit the significant decrease in the amount of CO2 entering the atmosphere, the global amount continues to increase. Whereby CO2 in the atmosphere is a key metric to measure humanities success in reducing its impact on the natural environment which has led to planetary instability. As consequence, at least 6 of the 9 planetary boundaries have been surpassed whereby the climate crisis represents one of these boundaries. UN Climate Change Executive Secretary at COP28 Opening speech

"We are taking baby steps. Stepping far too slowly from an unstable world that lacks resilience, to working out the best responses to the complex impacts we are facing. We must teach climate action to run. Because this has been the hottest year ever in humanity. So many terrifying records were broken. We are paying with people's lives and livelihoods".[20]

Time has run out action is to be taken climate records have been shattered and we humanity need to take urgent steps now. The following section introduces the SCT theory and the 12 design considerations as a systemic approach to advance CE and accelerate transformation towards net zero. The SCT proposes an integrated approach and (Re)frames the built environment issue solution space as needed to steer away from the globalized model[21] towards new socio-technical-economic models through design of more intuitive relationships between humanity and nature to improve opportunity to attain net zero goals.

A BALANCED WHOLE SYSTEMS TRANSFORMATION SPURRED BY CIRCULAR ECONOMY

To achieve a transformation to address the issues of climate and other critical planetary boundaries, a design process is Re(framed) by the Sustainable circular transformation theory,[22] with intention to improve humanity's relationship with the natural environment by changing the industrial production model to the CE.[23] To achieve this a whole systems perspective is generally agreed to be necessary.[24] Whereby a whole system approach can benefit from a balanced transformation across social economic and natural environmental aspects[25] as represented in the sustainable development concept.[26] The circular economy (CE) concept is generally agreed to be vital to transition towards net zero and sustainability.[27] In this study the SCT theory is applied as it uses the frame of sustainable development[28] as representative of a balanced whole systems approach and integrates the CE concept to innovate technical change across the entire lifecycle of resource and material usage, reuse and recycle (R strategies), with intention to reduce use of resources, and creation of pollution and waste. By integrating the CE into the SD frame, the SCT theory is expected to advance CE and accelerate towards net zero by including social and economic aspects.[29] This study investigates the applicability of the theory and the 12 design considerations to the built environment. The study is guided by the following research questions:

RQ 1 How can the SCT approach contribute to restorative built environment projects for net zero transformation?

RQ 2 How can social and economic design considerations contribute to net zero transformation?

Sustainable circular transformation theory (SCT)

The SCT approach[30] forms a systems foundation to benefit from a design and innovation process with practical design outcomes to improve transformation towards circularity and sustainability for thriving society and flourishing humanity.[31]

Definition SCT theory

A dynamic system consisting of three interrelated dimensions – the social, economy and natural environment – and through changes in these relationships as spurred by the circular economy R strategies seeks to restore and regenerate social and environmental conditions to transform for long-term wellbeing, diverse and sustainable societies within the boundaries of the planetary life support system, in a fair and equitable way.

(The definition draws from previous scholars including Stengers (2015);[32] and Konietzko et al. (2020).[33]

It is the CE R strategies (Reduce, Reuse, Remake, Recycle),[34] which disrupt the system with intention to reduce use of virgin materials, production of pollution and waste, using ordered strategies of reuse repair remake recycle – whereby recycle is only used when all other CE strategies have been exhausted.[35] See figure 1 CE R strategies are on the right hand side. The changes in the CE industrial model, R Strategies,[36] flow initially from right to left to impact the economic and social dimensions, which then react with outcomes, as influenced by design considerations, which flow through the system to update the economic and CE aspects.

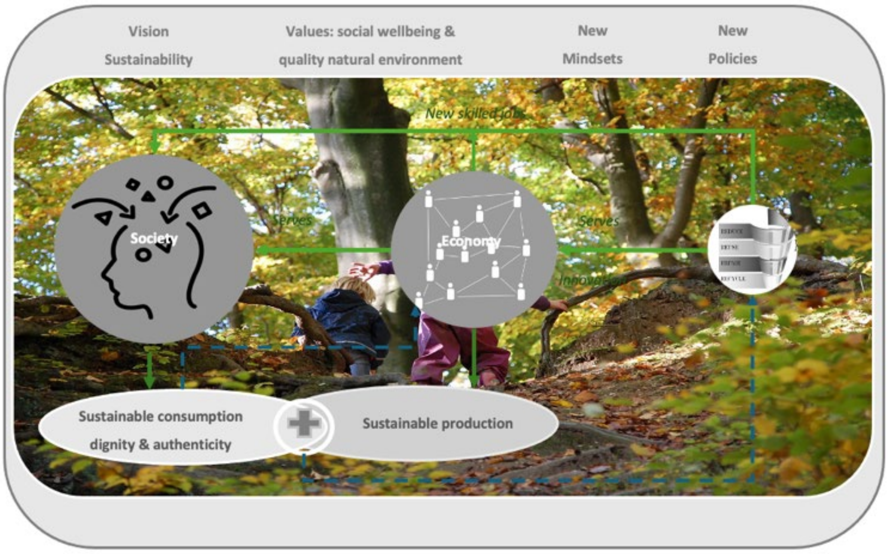

Figure 1. Evans. S adapted Evans 2023 An integrated circular economy model for transformation towards sustainability. Journal of Cleaner Production

The approach is composed of 12 interwoven design considerations which guide inquiry and innovation for a CE with intended outcomes to promote the wellbeing of people community and the natural environment, see Figure 2.

META
1 Systems level change over the long term
2 Vision and values for sustainable circular society:
3 Nuanced Policy
4 Adaptive mindsets
SOCIAL
5. Education-Learning of new skills; Acquisition of knowledge
6. Access to information
7. Progressive technology development
8. Sustainable consumption *(mindset)*
ECONOMIC
9. New and diverse economies
10. Equity and equality
11. Sustainable production (mindset)
NATURAL ENVIRONMENT
12. Sustainable production (industrial model)

Figure 2. Adapted Evans (2023) An integrated circular economy model for transformation towards sustainability. Journal of Cleaner Production, 388.

The economy by contrast to business as usual represents a more cooperative structure, collaboratively and codesigned, in this format there is a much stronger distribution of wealth, decision making to support equity, quality and a just society,[37] with new business models as driven by the R strategies.
Social aspects require design considerations to boost learning of new skills, enable access to information, ability to keep up with technical advancement, along with open mindsets for behavioral flexibility for an alternative code of progress.
With a SCT approach, the CE R strategies drive new business models which open opportunity for diverse economic models , which shape society, where new socioeconomic models can change humanities relationship with nature.

METHODOLOGY AND METHODS

A codesign process is Re(framed)[38] and guided by the SCT for outcomes of sustainability and circularity as frequently represented as thriving societies and flourishing humanity.[39] The 12 design considerations figure 2 are used to inspire imaginative, innovative inquiry among active stakeholders,[40] engage in productive dialogue with design outcomes.[41] The design considerations are used in an abductive manner moving thought processes between the real world issue situation space and the design consideration and in this manner able to contribute to codesign whole systems design proposals.
The description of the case investigated in this study is: a built environment restoration design project in the community of Hackney London. The project codesigns iterative proposals through the integration of diverse stakeholders including: leaseholders, directors, building management, service enterprise providers, council planning and policy makers, expert advisors including topics of circular economy, sustainability and net zero across multiple disciplines including designers, architects, engineers, solicitors, web site developer and real estate management.
Aspects of the building which situate the issue solution space:
• Renovated factory 26yrs ago
• 99 residential flats plus garage, commercial space
• Conservation zone
• Building aspects reaching end of life
• Opportunity to Re(frame) design approach for sustainable circular transformation

• Design experimentation set to improve wellbeing of people and quality natural environments
• Apply CE R strategies for Net Zero building transition

Data is collected from a series of multi-stakeholder meetings. The researcher takes notes synthesizes and shares with the committee for iterations. The meeting minutes including dialogue and actions executed and planned for execution, are shared with the broader leaseholder audience via email.

The system of change

A system to improve the quality of residential life and reduce energy usage, pollution and waste outcomes, in the era of climate change, as guided by 12 design considerations across meta, social, economic and natural environmental dimensions to innovate Circular economy strategies and accelerate net zero transformation.

A net zero committee: Onboard diverse stakeholders

Mix of leaseholders and directors see figure 3 who share a vision and values. Generally agreed with a World view to adapt for climate change, promote technical changes for the building to address issues of climate change, reduce CO2, pollution and waste and improve quality of living and value of the building. This world view is a combination of a future of social wellbeing, economic stability and natural environment restoration and regeneration. These values ameliorate the net zero members.

Net Zero committee	Skills	Knowledge of building structure history environment	Decision maker	World view
Leaseholders				Adapt for climatic change Accelerate a transition to reduce C02 and lessen impacts of climatic change Retain quality of living and value of building
Business founder director	Broad range of management capabilities; relationship building. (Building Secretary previous building director)	High		
Architect owner	New builds; grade A EPC (Building director)	High	x	
Senior Engineer: large corporation	Organisation transformation to low carbon: net zero (technical)	High		
GP	Systematic; experience building own home ecologically	Moderate		
Senior, leadership academic	Systematic; involvement in high level decision making with positive contribution to Net Zero	Moderate		
Solicitor	Legal documentation ; building experience			
Marketing	knowledgeable of sustainable building products			
Academic practitioner action researcher	Design for sustainable circular transformation	Moderate		
IT specialist	Building director	High	x	
Web site developer	Web site development	Moderate		

Figure 3. Diverse committee members with a shared world view

Stakeholder System flow

The stakeholder system flows, figure 4, demonstrates the flow of information and the types of collaborations and cooperation required to be able to advance a net zero transformation and restore the building according to a circular economy and for the wellbeing of people.

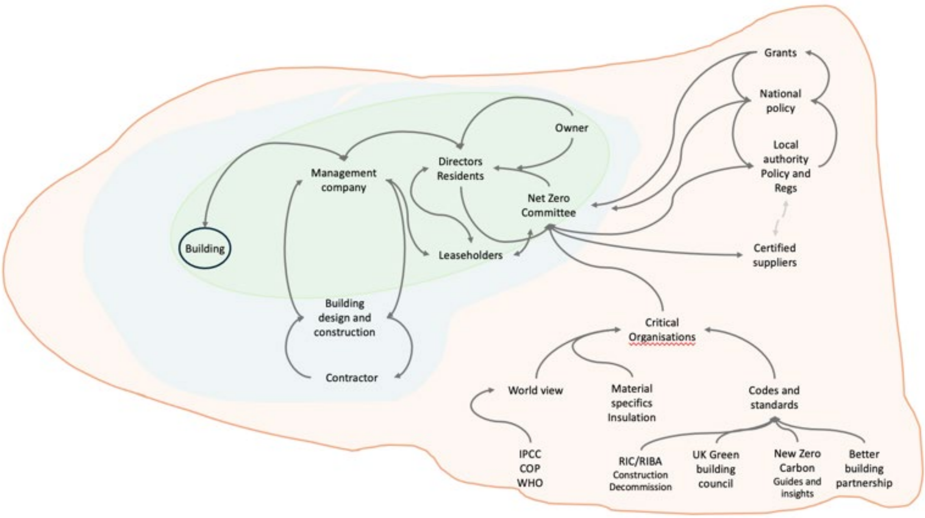

Figure 4. Demonstrates the stakeholder flow map with boundaries around the active and influencing stakeholders of the system

Restoration prioritization

Priority topic areas (figure 5) were proposed based on built environment actions for net zero transformation and then collaboratively prioritized and categorized according to building or leaseholder's responsibility. Topic areas drew from multiple authors, national and globally referenced environmental sustainability and net zero guidelines including the world green building council and IPCC.[42]

Item	Description	B.Dir.	Leaseholder	Primary action
Roof	*Interior* roof **insulation** *(cavity)*	x		x
	Exterior roof: Insulate	x		x
	(option) with **urban farm/garden**	x		
Wall	*Interior* wall Insulation		x	
	Exterior wall insulation	x		
Natural	Medium (or large) **Trees**	x		
Window	*Exterior* window **Shades**	x		x
	Interior window shades		x	
	Panes - Double /triple **glazing; secondary windows**		x	
	Window *frame* (floor consideration)	x	x	
Energy	Roof Photovoltaics/solar	x		x
	Heat pumps 5th floor deck (fuel cell boilers? hydrogen)		x	
	Heat pumps ground floor (fuel cell boilers? hydrogen)	x		
	Heating internal (space heating)		x	
	Water heating tanks/immersion	x	x	
	Lighting & decoration	x		
Ventilation	Interior flats (HEAT)	x		x
	interior hallways	x		x
Water	Building methods to reduce (Individual meters)	x		
	Internal methods to reduce water usage.		x	
EV Garage	Electric car charging	x		x
Care	Building structure exterior			
	Operational exterior and interior windows, doors, lighting, access safety plus			
Policy Planning	Council planning to **move towards Net Zero**			

Figure 5. Restoration area prioritization

RESULTS

Chronological event map summary: Figure 6

This slide demonstrates key design considerations at the meta level which impact advancement: namely mindset and policy as related to topic and stakeholder progression.

Policy and mindset represent specific preconditions required to spur circular economy advancement. Without decisive and strong policy decisions with supporting regulations – sustainable circular transformation decisions are far less likely to be agreed upon and are found to take longer to make decisions. Policy is neither strongly connected for production cycles and even less so for consumption cycles. Lack of clarity makes the nexus of the two cycles, new production methods requiring different consumption behaviours, foggy which slows down transformation progress.

Collaborative and continual effort required to move the concept of Net zero from back of mind towards active building implementation plans.

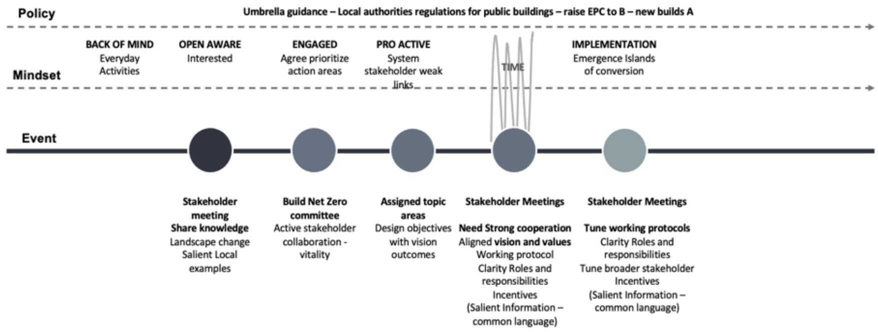

Figure 6. Chronological event map summary.

Summary analysis according to meta, social, economic and natural environmental design considerations: Figure 7.

	Reflection initial state	Experimentation SCT implementation
Meta	Short term view Policy: narrow technical focus Lacks incentives to spur and ease adoption Hindrance gaps between policy and implementation Mindset adaptation obscured by short term activities responsibilities	Critical to reset long term vision and values Nuanced multilevel sector, classification relevant and situated policy: spur design for social economic and natural environmental considerations Critical to engage and negotiate with stakeholders; introduce short and medium incentives to attain long term goals
Social	Mixed knowledge and skills General different application of expertise skill sets – under very different conditions More work to acquire new knowledge, share knowledge, to enable implementation	Build knowledge: website development for leaseholders and regular meetings with design probes among active stakeholders Engage stakeholders with relevant salient incentives: i.e. living conditions; value of building; contribution to net zero and natural environment regeneration
	Access to information: cluttered; distributed Lack knowledge/skills to make informed decisions on Technical information	Tailored salient relevant situated building information Bridge the gap between policy, goals and implementation: what can do with how to do it and ability to do it Influence mindset and behaviour change
Economic	Not yet addressed	Propose prioritize suppliers with cooperative business models support equity and equality
Natural environment (technical)	How to get started?	Lens of circular economy R strategies with critical socioeconomic considerations

Figure 7. Summary initial state and experimentation SCT implications.

FINDINGS

The design process revealed and aligned with previous scholarly work on systems design including benefits from a)integration of multiple perspectives, skills and expertise; b) levels of uncertainty which inhibited progress; c) requires alignment of stakeholder interests,[43] a shared world view; d) need for a working protocol[44] clarity of roles and responsibilities to advance CE and accelerate towards net zero.[45] In addition to previous findings this study recognizes the contribution of social and economic design considerations for a whole systems transformation by defining and experimenting with the twelve design considerations.

With a balanced systems approach across social economic and natural environment a more extensive set of solutions were proposed beyond technical changes, these included the engagement of a wide stakeholder base, products/interface design and additive guidelines for selection of preferred service providers. Specifically:

Social design considerations led to a website development to inform and advance leaseholder capabilities for implementation of net zero building adjustments. Barriers are beginning to dissipate with increased understanding and dialogue. This is part of a two pronged approach to improve wellbeing of people, community through building restoration which in parallel is expected to reduce impacts on the natural environment.

Economic design considerations led to guidelines for choice of service providers, contractors beyond "value for money". Preferences set for cooperative economies; local business; designs for longevity reusability and recyclability, regenerative resources, non-toxic materials. These guidelines have not yet been tested although expected to improve wellbeing of people and local communities by distributing wealth and reduce impacts on the natural environment by seeking local service provides, regenerative resources, product longevity designed with reusable and recyclable materials

DISCUSSION CONCLUSION

There is now pressing need to accelerate restorative transformation of the built environment to both adapt for the consequences of climate change and to reduce use of resources and amounts of pollution and waste and to do this in ways whereby everyone benefits and is included in the process.[46]

This study demonstrates the SCT approach for built environment restoration. It takes a whole system perspective and applies the CE to disrupt the system by changing the industrial production model for outcomes of circularity and sustainability.

In the past built environment restoration has focused on the technical changes, while this study presents an argument for the inclusion of critical social and economic design considerations which are reported to advance CE technical change, by engaging multiple stakeholders contributing different aspects to the system of change. In this multi apartment private block, this includes engaging multiple stakeholders, leaseholders, management company, building directors, service providers, in the system of change. This is achieved by reflecting on social and economic design considerations to codesign salient information as required by the different stakeholder groups in forms of – new skills and knowledge, and to make this new information convenient to access and apply to CE projects for net zero.

While the study is in its early development results demonstrate that different stakeholder groups are beginning to self-organize to collaboratively act (Rip 2006) with cooperation progressively improving between and within stakeholder's groups. This has been accomplished by regular serial multi stakeholder meetings, persistence to dig deep and across the system of stakeholders, to understand best practices, an openness to share new knowledge, build together and propose practical design solutions, with flexibility and a willingness to iterate.

In this study leaseholders are given the tools to be able to take action in their own built environment spaces by having access to salient information to propel them from what could be done (the observed initial status), to what is needed to tackle the issue and how to do it with suggested service providers who have demonstrated success in implementation and are trusted among the local community.

This approach is one way to inspire broader communities of stakeholders, who aim for net zero, to take innovative action for wellbeing of people and natural environment. It achieves this by removing uncertainties in building restoration to advance comfort of living quality in the time of climate change. To answer the research questions:

RQ 1 asks "How can the SCT approach contribute to restorative built environment projects for net zero transformation?"

The SCT can be applied to advance systemic transformation of the built environment towards net zero. The SCT 12 design considerations provide a guide to innovate a balanced built environment transformation as disrupted by the CE. Table 6 reports on the initial status and the experimentation according to the SCT for transformation of the built environment.

RQ 2 "How can social and economic design considerations contribute to net zero transformation?"

The contributions have been discussed under findings. In summary: with inclusion of social and economic design considerations a more extensive set of design solutions were proposed beyond technical innovative changes, these included the engagement of a wide stakeholder base, products/interface design and additive guidelines for selection of preferred service providers. These codesigned outcomes as shared with stakeholders have been positively received and are already advancing CE dialogue and understanding for transformation to net zero.

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HUMAN HEALTH AND BUILDING MATERIALS: A HOLISTIC VIEW ON TYPICAL BUILDING MATERIALS AND APPLICATIONS

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INTRODUCTION

The use of hazardous materials in buildings has been a concern for decades. Prior to the discovery that some materials are more hazardous than others, they were common use in construction. For example, the decision to ban some asbestos uses from future construction buildings was done in 1989 by the Environmental Protection Agency (EPA). Specifically, in buildings built before this ban, these materials have been common use in construction. In contemporary interior architectural design practice, the possibility and practicality of reusing the materials in the original building have been evaluated and studied with an attempt of restoring and retaining historical structures. By understanding the life-cycle and the social, economic, and environmental factors of a building, the hazardous materials have the opportunity to be repaired, remanufactured, or repurposed. By preventing waste from entering a landfill,[1] there is a positive impact on the surrounding community and the well-being of the building occupants.

APPROACH FOR MINIMAL ENVIORNMENTAL IMPACT

In order to accomplish sustainable design for future generations, we must design with the idea of minimal impact on the environment. This idea would be consistent throughout all phases of design, construction, and inhabitation. To that end, interior architectural designers should consider the role of the overall product life-cycle. The life-cycle starts from the creation and production, to transportation, installation, use, removal and disassembly. When considering removal and disassembly it is essential to understand the portion of the products that are recoverable and able to be reused. This cycle could be extended based on the product and material specifications. Therefore, designing for the environment and human well-being, implementing sustainable materials, and repurposing hazardous materials creates a continuous life-cycle of materials with little waste. In order to address these environmental and life cycle concerns, planning early in the process is integral. One example of this is the construction of Parson's University New School, located in New York City, NY, which was successful in preventing 91% of building materials from landfills. While diverting 6,800 tons of waste from landfills, the overall demolition process also considered the impact of demolition debris on the surrounding area.[2] This not only proves that ability for materials from existing buildings to be reused but also repurposed and diverted from landfills.

Hazardous materials are not only harmful to the well-being of the inhabitant, but also detrimental to the balance of the ecosystem. By defining hazardous materials and having a clear understanding of the life-cycle and impact they have on the environment, it is possible to assess how they can be reused and possibly repurposed. The reuse of hazardous materials as well as other harmful materials, for instance, could be implemented in place of other non-renewable resources. One example of this is the recycling of used building materials that are repurposed to extend the material life-cycle. In *Better Building Materials*, an open source guide created by the U.S. Green Building Council, the life-cycle of the material is viewed as a closed loop system that allows for the reuse of or sustainable breakdown of materials that should be used in buildings, which can be seen in figure 01.[3] Through regulations in construction and the culture of the design process to value reused materials, it would allow for materials to be reused after demolition. These strategies would then spread as an ideal that should be met by all buildings as an advantage to current and future use of existing structures. Harmful materials have the ability to be safely reused in buildings and not pose a threat to human well-being while simultaneously the impact on the environment. This is evident through building materials that are re-purposed or materials alternatives that serve the same purpose but have a continuous life-cycle.

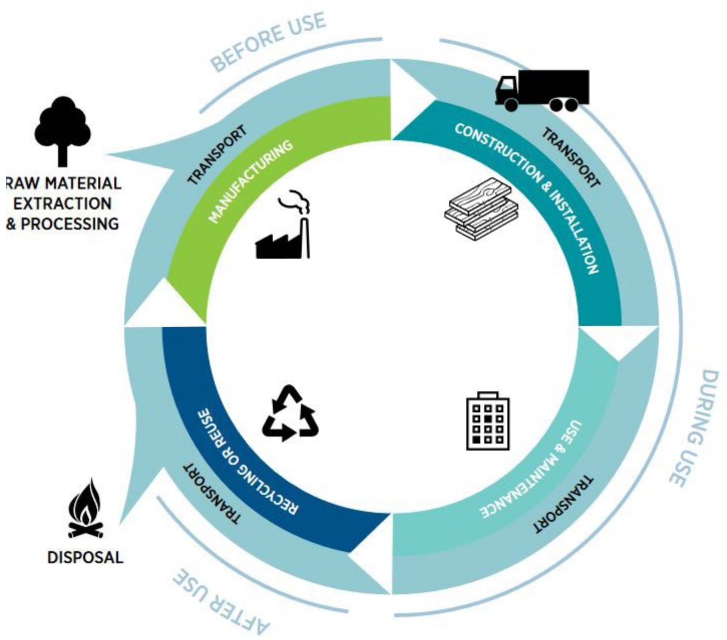

Figure 1. Material Life-Cycle
USGBC, Better Building Materials Guide, 2015

Natural resources are the only element that has multiple variations of use and reuse. Reiser and Umemto state that "Man is finite and so are his projects."[4] This idea relates to the idea that the materials we use to create are finite. However, with this knowledge, designers can be more deliberate about their material choices and the long-lasting impact. The material life-cycle dictates the origin and endpoint to which all materials last. Despite this limited life span, some products have created permanent damage to the ecosystem and human well-being. This is due to decades of mass production of goods and high demand for services. This created a stress on the environment to produce natural resources based on the increasing needs. The construction industry contributes "230 million to 530 million tons of C&D (Construction and Demolition debris) are produced nationwide each year,"[5] thus regulations have been created on the production of construction materials. Materials that "pose a threat to public health due to potential land and groundwater contamination" are considered hazardous not only to the environment but also the human well-being.[6] In order to ensure natural resources will be available for future generations, designers must implement sustainable solutions and repurpose hazardous materials. The variation of life-cycles of these materials leads to long-term damage to the environment that cannot be reversed.

SCOPE OF STUDY: THE LIFE-CYCLE OF HAZARDOUS MATERIALS

The current life-cycle of hazardous materials starts with production of said material and typically results in the disposal in specified landfills based on regulations set by the EPA. Due to the exposure to the natural elements generates waste runoff and pollution of the surrounding air, soil, and water. Focusing on the decades of waste increase through production and demand by the construction industry, we are left with depleting natural resources, an abundance of waste, and diminished ecosystems.

In order to properly reduce these material goods, we must understand the connection of mass production and the impact of these goods throughout history. These factors fall into line with the social, economic, and environmental factors of where it was created. The life-cycle of construction materials typically ends in the landfills that fit certain specifications, but the end of use does not mean that the material has completed its impact on the environment. This reduction of pollution as a by-product of hazardous materials is possible through "re-design of processes to eliminate the production of harmful by-products, or; the re-design of products to eliminate the need for those processes that generate harmful by-products."[7]

According to the Environmental Protection Agency, EPA, human beings spend about 90% of our time spent indoors.[8] This has a direct impact on the health and well-being of the occupant. The exposure of the materials through pollution and particles of hazardous materials directly impacts the air we breathe. Based on research of negative effects on the human well-being from VOCs, hazardous material run-off, and inadequate air-quality, restrictions have been made to prevent the use of these materials in spaces of possible exposure. For example, the EPA created a partial ban on the use of asbestos as insulation within home in 1989. This minimized the "manufacturing, importing, processing, and distribution of some asbestos-containing products." [9]

Nonetheless, buildings built before this ban have a higher chance of containing a form of asbestos. The demolition of these buildings releases the airborne particles that are easily transmitted to the surrounding area. Not only does the demolition cause a negative impact to the surrounding area, but also the long-term effects it has on the ecosystem. By examining the production and demand of materials that create hazardous by-products, there is an opportunity to use this by-product useful. For example, Atticus Durnell, an artist located in England, creates sustainable and biodegradable products from leftover coffee grounds. Fly ash, a by-product of coal combustion can be used in place of concrete. This extends the life-cycle of what would typically be disposed of. While materials such as coffee grounds and fly ash may seem more likely to be reused, asbestos can transform from a hazardous material to a non-hazardous material.

The life-cycle of these materials are viewed as disposable and non-reusable after its purpose has been served. Once it is no longer needed, it can be disposed of. With the innovative techniques and technological improvements extending these materials' life-cycle, there is an extension of the life-cycle from the original path that ends in landfills. William McDonough expands upon this idea of the end of material life-cycles through the materiality of his book Cradle to Cradle. Something as simple as a physical book, made from paper could hold more detail and depth through the materials of the pages you turn as you read. He starts by stating that 'This Book Is Not a Tree.'[10] He evaluates all aspects of our surroundings through materiality. The dyes, chemicals, metals, and more create a chair we sit in, but the process in which these materials could be considered toxic and hazardous to human well-being. Movement can displace particles into the air we breathe, but we may not have been aware of this during our purchase. He expands upon this idea by using his book as an example of synthetic 'paper' that has been bound as a book. We have the experience of reading a physical book while being waterproof and durable. Despite this durability, this book can still be recycled and repurposed. The scope of life with something a small as a book creates a large impact on the ecosystem that we leach off of.

The practice of implementing the scope and life-cycle of materials throughout the design phases is best when viewed early in the phases. When extending the life-cycle of materials is the goal, environment and cost go hand in hand. By utilizing this ideal, firms typically look at the trends of consumers. Life-cycle Cost Management (LCCM) has a goal to "save money by making purchases, operating, and maintenance decisions based on the full life-cycle cost…"[11] The finances evaluated typically include the product or materials "acquisition, use, and ultimate disposal, including costs of storage, transportation, facilities, energy, labor, training, and record keeping."[12] These are all different aspects that may vary the life-cycle of a product or material and how it is included in the design. This can be seen in figure 01. For example, the sourcing of wood typically requires the use of proper foresting while not depleting the natural resources in a specific area. By selective removal of the natural resource, there is opportunity to continue the growth and ensure that there are enough resources for future use. The use of wood treatment also dictates the life-cycle of the material. By using harmful varnishes, there is a smaller opportunity to reuse the product. The craft of the product determines the life-cycle of said material. Reiser and Nanako state that:

"Craft, therefore, does compromise a natural response to material necessity, be it the organic moments in mechanized process, the rapid prototyping of mass-produced components that takes place in an auto production, or the customized, one-off at Lockheed' SkunkWorks program. Rejection of craft, therefore, is reactionary and cannot be justified by an ideological platform that purports to reinvent production without recognizing the distribution of craft practices."[13]

The mass production of materials for conveniences and high demand diminishes the natural form of the material. The loss of individuality was lost during the mass production of products and materials, creating lower quality goods and the ease of disposal of single use items.

Historical Background: Mass Production and the Production Industry

The impact of the construction industry on the environment is drastically different from that of the consumer population based on demand and scale of projects. The demand for these materials and goods creates a strain on natural resources as well as long-term effects. This trend has been established for centuries from the First Industrial Revolution to the Fourth. The First Industrial Revolution started in the 1700s as a transition from a handmade production process to a mechanical based production. This new process was implemented for the speed of production, the accuracy of assembly, and the positive economic impact. This surge of new production processes and machinery increased the use of hazardous and non-reusable materials. With the continuation of the Second and Third Industrial Revolutions, the quality of the materials and products were not considered for longevity and durability, but for profit and ease of production. Due to the increase in demand of products, the United States, for example, created a greater focus on solving problems for production after development. This leads to "low-quality products, high product development costs, and innumerable delays getting a product out to market."[14] By analyzing these mistakes and the effects it has not only had on the economic system but also the ecosystem, we have evolved the Fourth Industrial Revolution to resolve some of these mistakes. According to Neri Oxman, a designer and professor at MIT in Massachusetts,

"The Fourth Industrial Revolution heralds a series of social, political, cultural, and economic upheavals that will unfold over the 21st century. Building on the widespread availability of digital technologies that were the result of the Third Industrial Revolution, or Digital Revolution, The Fourth Industrial Revolution will be driven largely by the convergence of digital, biological, and physical innovations."[15]

The use of hazardous materials increased due to the Industrial Revolutions. This is due to the high demand of products, whether it be construction materials or everyday household goods. Mass production created an influence on everyday life. There are products that have been accustomed to be a 'one-time use' for ease and convenience. For example, a cup of coffee is created by the demand for coffee shops and their clientele. This allows the customer to receive their drink to go, while being on-the-go. The cup is easily discardable and suits their needs immediately. The process of making the coffee and the cup itself are different, but the end-point of both are similar. Coffee ground, when disposed of in large amounts, generates about "2 million tons of CO2 emissions."[16] The cups are typically not recycled, despite the push for recyclable materials they are made out of. The idea of recycling does not directly mean an infinite amount of uses after it is discarded. These materials have a finite lifespan when properly disposed of. By examining the timeline of building materials, the progress of non-organic additives has grown exponentially with the introduction of the rapid production, as seen in figure 02. This can also be viewed as low-quality furniture, typically used for short periods of time and disregarded when no longer needed or damaged.

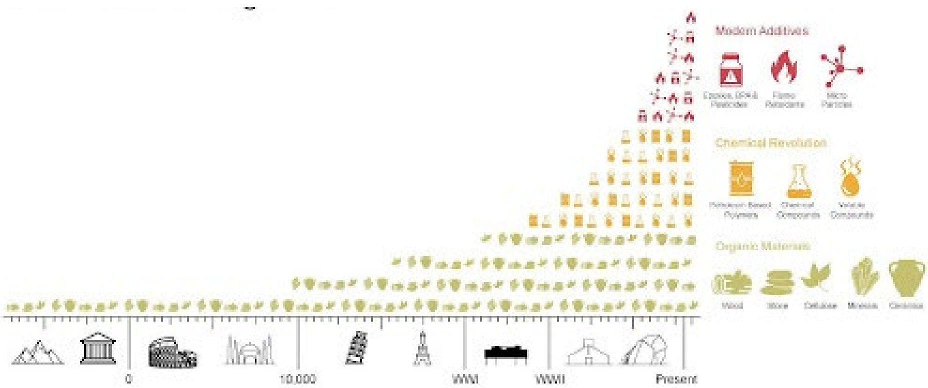

Figure 2. Timeline of Building Materials
Parsons Healthy Materials Lab

During the twenty-first century, we are experiencing The Fourth Industrial Revolution. The change in the production cycle has incorporated the use of more reusable materials and production is more mindful of its impact. The improvement of technology and its influence in production has created the opportunity to design and improve human abilities. The use of designing through mechanized systems has been in use by the turn of the twentieth century by architects such as Louis Sullivan and Ludwig Mies van der Rohe. By expanding upon the technological evolutions of the "integration of biology, technology, and design," we can expand design practices that mimic natural geometries and processes.[17] This can be seen through medical explorations to expand from what we create naturally to modifying this idea and creating natural elements and controlling the process of these designs.

REGULATING SOLUTIONS

As systems developed and new technologies arise, we become more aware of the harm that many materials have on human well-being as well as the environment. The EPA has played a critical role in the regulations regarding hazardous materials. These regulations are based on the impact it has on human well-being after being exposed for both short and long periods of time as well as the lasting impact it has on the environment and ecosystem. Currently, there are specific locations for disposal of hazardous materials, but that can create runoff that harms the surrounding water and soil. This ensures that hazardous materials, such as asbestos and other waste from construction do not further harm the surrounding area.

Industrial disposal and construction and demolition waste create the majority of the waste in landfills. A large portion of this waste includes "sludge, oil, slag, ash, food processing residues, solvents, metals, and plastics, with a significant quantity of being hazardous."[18] These varying degrees of hazardous waste have been recycled industrially in order to process them for different uses for a profit. These byproducts have potential to be hazardous and pose a threat to the user, but that is calculated within the cost of recycling. This discourages the reuse of hazardous byproducts. "Waste generated in the early stages of production is generally high in volume and low in resource utility…"[19] This can be seen through the extraction of natural resources or raw materials mined and excavated. Despite this liability, there is an opportunity to treat these hazardous materials and byproducts to become non-hazardous to human well-being and become a burden on the ecosystem. For example, by heating "asbestos-containing materials in a sodium hydroxide solution above 1,250 degrees Celsius to break down asbestos" to a non-cancerous product. [20]

Regulations regarding material extraction, processing, manufacturing, use, and waste management have been created based on their overall impact on the ecosystem.[21] By creating a sequence in which we develop our designs through materials, the problem in which we have faced through climate change and depleting natural resources can be further mitigated. This sequence of architectural construction includes extraction of raw material, modules, elements, structures, the structure itself.[22] The "Developments of lightweight, high-strength, and high-performance materials offer the prospect of economy, efficient transport, re-use, and less waste all of which streamline the process cycle."[23]

These developments create a new process through the design sequence. The process in which new structures are designed should include the life-cycle of the materials used. Kieran and Timberlake state that "We need more information early on in the process of conception in order to project cost, method, and sequence of assembly into our design considerations so that they will act as positive constraints that make our design solutions powerful because they are lean."[24] The "mass customization of architecture" allows for the details to be customized by project. This allows designers to hone in on the material details along with a wide range of products that are durable, reusable, and non-hazardous to the ecosystem or the human well-being.

SCALE AND SCOPE

In order to build sustainably for future generations while restoring and retaining historical structures, we must analyze the reuse of the materials in the original building. The use of toxic materials in buildings has been an issue for decades. What was once considered a good insulation, is now harmful to the user. Specifically, in older buildings, these materials have been common use in construction. By understanding the building life-cycle as well as the life-cycle of the material, the material has the opportunity to be repaired, remanufactured, or repurposed. This all varied based on the social, economic, and environmental factors of the build. By preventing waste from entering a landfill, there is a positive impact on the surrounding community and the well-being of the occupants.

To accomplish sustainable design for future generations, we must design with the idea of minimal impact. This idea would be consistent throughout all phases of design, construction, and inhabitation. In order to achieve this ideal, we must consider the role of the social, economic, environment, and cultural impact this shift in design would have. By designing for the environment and climate, implementing sustainable systems, such as passive systems, would be properly taken into consideration as well as characteristics of the existing structure. The architectural design process is a sequence of communication, documentation, construction, and occupancy with the stakeholders, builders, contractors, and other design professional. The sustainable design process starts with understanding the needs of the stakeholders while educating them on sustainable practices that will benefit the stakeholder, the occupants, the community, and the environment. The implementation of healthy building material education in the architectural design process allows the stakeholder and occupants to understand the materials, elements, and chemicals they are exposed to while occupying a structure, as seen in figure 03. This will ensure those that occupy the building will have the ability to choose the materials and understand the implications each material will have on their long term health.

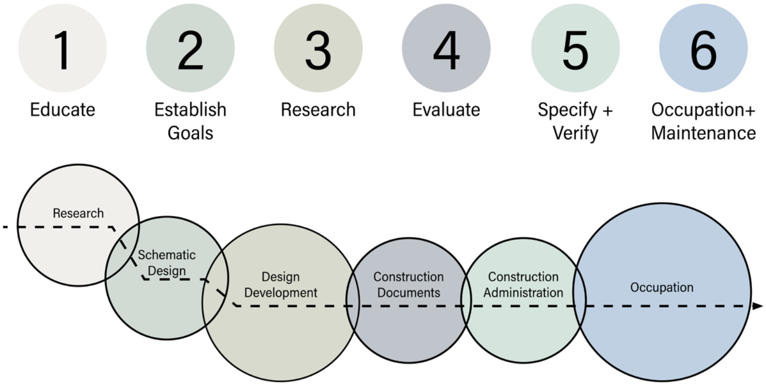

Figure 3. Alignment of Architectural Design Process and Material Health Hagan. 2024.

The existing characteristics of the building may be valuable to the society and culture of the area as well. By retaining the sense of history in such a place while revitalizing and tailoring the interior spaces and new programs will develop necessary solutions to the problem at hand. Analyzing the contextual environment and designing with that in mind, allows us to develop a quality of space that would suit the existing site and the cultural tie to the community. Through these new design implementations, it would draw new users to the area and site which would also implement behavioral changes to the users when they are faced with sustainable design strategies. These strategies would then spread as an ideal that should be met by all buildings as an advantage to current and future use of existing structures.
Not only is the scale and scope of the material based on the social, economic, and environmental factors, but also on the way in which it can be repaired, remanufactured, or repurposed. Fly ash has been used for more purposes beyond architecture. Erica Stines, a designer, has designed and created chairs that utilize fly ash for furniture pieces.[25] Fly ash has been used in architecture as a more durable and lightweight material in place of concrete. The Daniels Building at One Spadina Crescent uses fly ash in an adaptive reuse project which absorbs more moisture and is more weather resistant than cement and is more durable and resistant to movement. This extends the lifespan of the building as well as the material's longevity in relation to the weather conditions. Fly ash uses the byproduct of coal combustion, creates a material that does not deplete more natural resources, as well as lowers the carbon footprint of hazardous materials when reused.

PRACTICE AND APPLICATION OF HEALTHY BUIDLING MATERIALS

The implementation of healthy building materials is not a new topic of research. This practice has been implanted in countless structures, from large-scale mixed-use buildings to small scale residential buildings. In the spring semester of 2024, a college level building technology course consisting of 39 students were tasked with research thirteen case study projects. While the program band scale of each case study varied, the ideology of each project was similar; to create a healthy and sustainable space for both the occupant and the environment. The buildings had various certifications, whether it was

Leadership in Energy and Environmental Design (LEED), or Passive House Institute US (PHIUS), or other notable energy certifications.

Throughout the semester, students researched sustainable aspects of their selected case study by examining the building envelope, interior conditions, structural components, and material selections. From this research, the students sourced one material relating to the building envelope, interior finish, and a structural component, creating a library of 39 materials that are either exact samples of the specified material or a similar product, as seen in figure 04. By creating an understanding of the original building and the layers that create it, one layer that plays a major role is one on the user and the connection to the community and culture of the place.

Figure 4. Exhibition of Material Research
Hagan. 2024.

The multiple layers of a building, both physical and metaphorical, that must be analyzed before successfully proposing it to a stakeholder. By pealing back each layer of the building and analyzing the materials, both visual and chemical connections will have a lasting connection on the occupant. There are the physical attributes that allow the building to withstand the elements and surpass time. These physical attributes will allow us to understand the time it was built not only by the design but also the materials used for structure, insulation, and decoration. The metaphorical elements that contribute to the design relate more to the program, the history of the place, and the connection to the community. While peeling these layers apart, the materials used is one layer in particular that will have the greatest impact on both the occupants' health and the environment. The human connection to buildings is deepened by their senses, whether it has been fifty years or 10, there is still an impact on the community that surrounds this building. Its memory is embedded in the fabric of the community. If that connection is weakened by lack of use of disheveled materials, there is a possibility of the connection to be regained. We form a bond with memories and senses of places that are passed on throughout a community.

DESIGNING FOR DISASSEMBLY AND REUSE

Designing for Disassembly (DFD) is a main concern in the design problem itself. This includes, but not limited to, production, transportation, and installation. The disassembly of a material is considered by how it reacts to the elements, general wear and tear, and cutting down on landfill use. Throughout the design process, the material impact and the role it plays in the construction should be considered for the life-cycle of the materials used. The design problem we are facing in the twenty-first century is the impact and role this plays on the ecosystem and the resources for future generations. Since the materials we use and the products we design are finite, the life-cycle of the material plays a crucial role in the lifespan of the building itself. By designing for assembly and disassembly, there is a greater opportunity to reuse the materials to expand the life-span. Through adaptive reuse, there are many materials that are to be conserved based on historical significance or connection to the community. Sally Stone explains the important role that historical adaptive reuse has in materiality and the surrounding community. She states that:

"Buildings and monuments are valued for their historical age and their aesthetic appeal. Both aspects are highly contentious. It is questionable whether a structure should be valued just because it is old, while aesthetic significance is directly connected with the culture that is making the assessment and thus subject to the whims of society." [26]

When designing for new construction, William McDonough explains the life-cycle of a material and the relation of the Triple Bottom Line. The Triple Bottom Line creates a tripod of approaches based on ecology, equity, and economy (fig. 02). McDonough states that businesses typically design baked on profit while incorporating certain aspects of the Triple Bottom Line "with social or ecological benefits considered as an afterthought."[27] There is little equality to this thought process when there is a heavy consideration on the profitability of a design with some ecological benefits. In Figure 04, there are different portions of the Triple Bottom line that create this consideration in this design process, but there is an opportunity to create an equality of the three points. By adaptively reusing materials in construction, there is less waste in landfills as well as creating a dialogue with the community. In order to properly reuse a material, we must understand "prevent solid waste from entering the landfill, improve our communities, and increase the material, educational and occupational wellbeing of our citizens..."[28] This connection to the community involves those that use the building and create a better understanding of these materials on their surrounding ecosystem.

By implementing the Triple Bottom Line in the design process early on, there is a better understanding of how we can use materials beyond what was originally thought of as the end of their life-cycle. There is opportunity for expansion of these materials for future use or to be biodegradable with little to no negative impact on the ecosystem. Two ways in which we can design for deconstruction is by understanding remanufacturing and the current limitations we have on material reuse. Remanufacturing creates an opportunity to "recycle a material in their "highest value" recovered state."[29] Based on the quality condition of the material, there is a greater chance to reuse said material. Materials that have limited lifespans based on use, such as ink, or materials that disintegrate by temperature and exposure to environmental elements. The lifespan of most materials is not a straight line, but branches off to separate possible uses. The origin of the materials may be similar, but the uses vary and separate through different portions of use and exposure to the elements seen in figure 03.

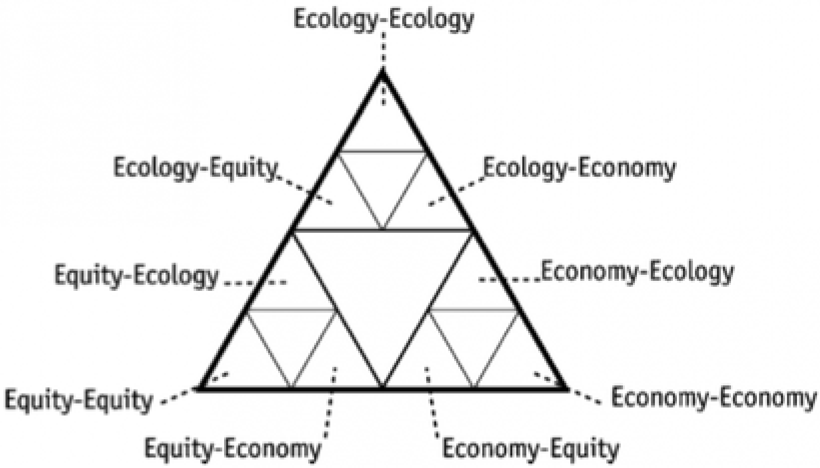

Figure 5. Triple Bottom Line
McDonough Cradle to Cradle. 2002. Triple Bottom Line.

CONCLUSION
To curtail the negative effects of these harmful materials on the ecosystem and humans, we strive toward sustainable and healthy solutions. Despite the non-linear life cycle of materials, we are able to understand different points in which the material plays a role on the environment, as well as human well-being. Neri Oxman, designer and professor at MIT Media Labs, has created "Nine Commandments for a Material Ecology," advocating principles that guide her design process and the relation it has on the natural environment. Two of these commandments, Decay over Disposal and System over Object, view the products designed as "part of a system of interrelationships between natural and designed environments including interactions between the entity and the human body as well as the entity and its environment."[30] This connection to the natural and built environment creates a bridge between the ecosystem and the effect of the built environment. The materials used would rejoin the ecosystem in a circular life-cycle. Oxman designs products based on the use and how it creates a relationship with the user. She states that, "The product - be it a product, a wearable device, or a building - is considered part of a system of interrelationships between natural and designed environments including interactions between the entity and the human body as well as the entity and its environment."[31]
By prioritizing the challenges and risks that most commonly used building materials have on human health, integrating practices that focus on human health early in the design process will minimize the potential threats to occupants. Despite the push for heathy food that is produced with little to no harmful chemicals, it is equally important to consider the chemicals used in the production of building materials. The same level of scrutiny and caution should be applied to all aspects of the architectural and construction process, not only for the environment, but also for the long-term health of the occupants.

NOTES

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[2] The American Institute of Architects. *University Center - New School*. 2020
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SECTION FOUR

THE MORPHOLOGICAL TYPOLOGY OF THE PRODUCING CITY: AN INVESTIGATION OF MORPHOLOGICAL CRITERIA FOR THE DEVELOPMENT OF A TYPOLOGY AND REINTEGRATION ON URBAN FORMS OF PRODUCTION

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INTRODUCTION

This research addresses the challenges faced by German cities in transforming their inner-city areas due to structural changes driven by shifts from industrial to knowledge- and service-oriented economies. The study investigates the morphological typologies of production facilities by considering the spatial dimensions of production processes and existing urban structures. Through the application of clustering and spatial analysis, the research aims to identify the potential of reintegration of industrial production areas within urban contexts and their role as catalysts for creating mixed neighbourhoods that contribute to urban sustainability.[1]

Background

Experts in Germany discusses for the first time after 62 years, about the abolition of the separation of uses, which has been the legal basis since 1962 with the adoption of the Building Utilisation Regulation (BauNVO).[2] The interpretation of Corbusier's Charter of Athens from 1933 led to a segregation of living and working, which resulted in a process of displacement at the costs of the manufacturing industry.[3]

2007 at the Conference of the Leipzig-Charter, the discussion of a mixed-function city was taken up again to develop a response to the European goals of sustainable cities. The goals formulated in the charter are: manufacturing industry, craft businesses and corresponding jobs are to be secured or newly established. [4] Jobs should move closer to people's living environments and can therefore also contribute to reducing commuter traffic.[5] The multifunctional nature of the project is expected to have socio-economic stabilising and upgrading effects for the districts and neighbourhoods.[6] Economy and industry began research into production conditions in urban areas in various areas at an early stage. The development of renewable and low-emission to zero-emission energy sources, the 'Industry 4.0'[7] initiative for a decentralised and location- independent production process, as well as necessary adjustments in city administration and land-use planning to simplify inner-city branches, confirm the investigated option of urban production.[8]

STATE OF RESEARCH

The topic to be analysed is ambivalent due to its complexity and ramifications in various specialist areas, as well as the interaction between theoretical approaches, implemented practice and current developments.

The resumption of industry and commerce in an inner-city context was first discussed by the government and politicians in the 2016 German Sustainability Strategy[9] and introduced in a 2017 amendment to the German Building Code[10] as a new building area category "Urban Area – MU".[11] The possibility of different uses for individual storeys and a higher permissible immission guide value of 63 dB are just two of the innovations for achieving density and a mix of uses. Informational media on resource efficiency for urban production, addressed at businesses and companies, are intended to promote a feasible scenario for inner-city locations.[12]

The concept of the 'Productive City' is still in the early stages of investigation by urban and spatial researchers. The newly published research project 'New spaces for the productive city'[13] commissioned by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), includes an inventory of the topic and an attempt at a definition. The lack of a standardised definition highlights the need for research. The similarly described intentions of the productive city to achieve sustainable effects from integrated production in urban areas are particularly relevant to society.

"*The lack of low- skilled manual work in the inner city is linked to poverty, crime, family dissolution and the social life of neighborhoods" – William Willson, 1998* [14]

"The argument is that manufacturing cannot and should not be-delinked from typically urban „knowledge-based" activities such as design and R&D. Or to put it more strongly, a manufacturing base is a necessary condition to develop and expand R&D and other high-level-services." – Willem van Winden and Leo van den Berg, 2011 [15]

The Challenge of definition

The few existing studies on 'Urban Production' and 'Productive City' show a very small reference pool as a basis for investigation. Dr Nischwitz explains this in his study with the lack of a common understanding of the terms, as well as a lack of clarity in the definition.[16] Although the number of posts relating to the Productive City is not small at all. Urban Production is well defined through several publications, in the academic debate.[17] A consistent understanding of the term can therefore be assumed here.

Urban Production is a central component and a central requirement for the Productive City according to Nischwitz. Urban Production focuses on production in densely populated urban areas, that produces a physical product. So, to say: Things.[18] Technological advances enable it to produce with low emissions (noise, exhaust fumes and other negative emissions) and resource efficiency. It is integrated into local economic cycles and sales markets.[19]

Even the Federal Institute for Research on Building, Urban Affairs and Spatial Development in Germany understands urban production as: A production, or further as companies, that manufacture material goods in the immediate neighbourhood of residential locations.[20]

Various studies, such as the one by Piegeler/Spars 2019,[21] or the Federal institute, have already analysed city-related industries and their potential for an urban production. They specified industry sectors for urban production possibilities, based on existing production sites according to their spatial distance to population density (see figure 1).

Another approach is to create a first typology of the Productive City according to proportional distribution of utilisations. They mention for example light manufacturing industries such as nanotechnology, medical technology and small-scale mechanical engineering, consumer goods and food industries, as well as clothing and furniture manufacturing and breweries. [22]

It also covers information and communication technology, the health and creative industries and forms of urban farming. [23]
In contrast the Productive City as a normative concept, describes the mix of uses between living and working, particularly production, as an overarching concept. Urban Production is linked as a central component to create a mixed-use cityscape. [24]

Industry Sectors for Urban Production

Industry sector	Classification	Example
Agriculture	WZ A	Agriculture and forestry, fisheries
Manufacturing Industry	WZ C	Manufacture of foodstuffs, beverages, tobacco and textiles etc.
Repair of data processing equipment and consumer goods	WZ S95	Repair of telecommunications equipment, consumer goods, furniture and jewellery etc.
Construction Industry	WZ F	Property developer for residential and non-residential buildings, building construction, construction of roads etc.

(translated by Radounikli from source: BBSR 2022)

Figure 1. Industry Sectors for Urban Production

Research question

This research focusses on a very visible and spatial level. The question is: Are production facilities capable to coexist in inner-city structures? By production facilities we mean factories, sites, manufactories, places where material goods are created and produced. More precisely the building envelope required to enable a production process and all the needed programs, as well as the necessary outdoor facilities.
In the context of setting the framework, it is important to specify the investigated industries. The investigation focusses on industrial and serial production processes and not small manufacturers with individual Products. A specific quantity or batch cannot be named yet, to define the production size. This shall be a component to the question's answer.

METHODOLOGY

The method and tools in this study is based on three steps, which ultimately aim to provide a systematised assessment of production sites and their urban compatibility, in terms of spatially compatible quality for the location and spatially required quality for production needs. The keywords here are acceptable urban and human scale and added value for all stakeholders.

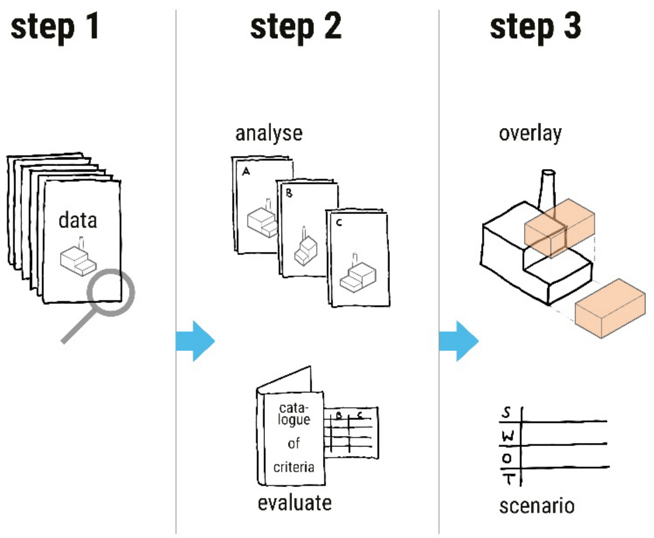

Figure 2. Methodical Steps by Alexandra Radounikli

Step 1 – Data Collection

The first step is extensive data collection of existing forms of production, through desktop research, and interviews with stakeholders. Project references on industry-related production locations are to be collected. In this process, the existing research on urban-compatible forms of production are used to qualify the reference pool as far as possible. At the same time, a preliminary catalogue of criteria will be developed through the research to enable an initial clustering and compilation.

Step 2 – Catalogue of Criteria

Second step is a structural analysis of the collected references. An analysis with subsequent evaluation of the identified criteria. Only after identifying and recording structural patterns and dependencies regarding urban compatibility and procedural necessity does it make sense to concretise the catalogue of criteria.

Following this the criteria are provided with evaluative indicators so the researched parameters can be rated in terms of urban compatibility and procedural necessity. The development of the evaluation system is an essential component of this doctorate. Recognising and assigning advantages and disadvantages according to spatial parameters is the key to a meaningful result.

The specification of the catalogue of criteria is therefore carried out iteratively with the development of the evaluation system. Urban and sociological relevance as well as process-critical parameters are the decisive factors here.

The single criteria are linked to an evaluative indicator that relates to the questions:

- Is it quality for the urban location/the people next to the facility?
- Is it required quality for production process?

By answering with yes, moderate, no or irrelevant it is possible to transfer this rating into a diagrammatic scheme.

Step two, aims to make an initial statement as to which form of production and the associated spatial requirements are most likely to fit into an existing urban structure. Which urban form of production generates the highest added value and the least potential for conflict?

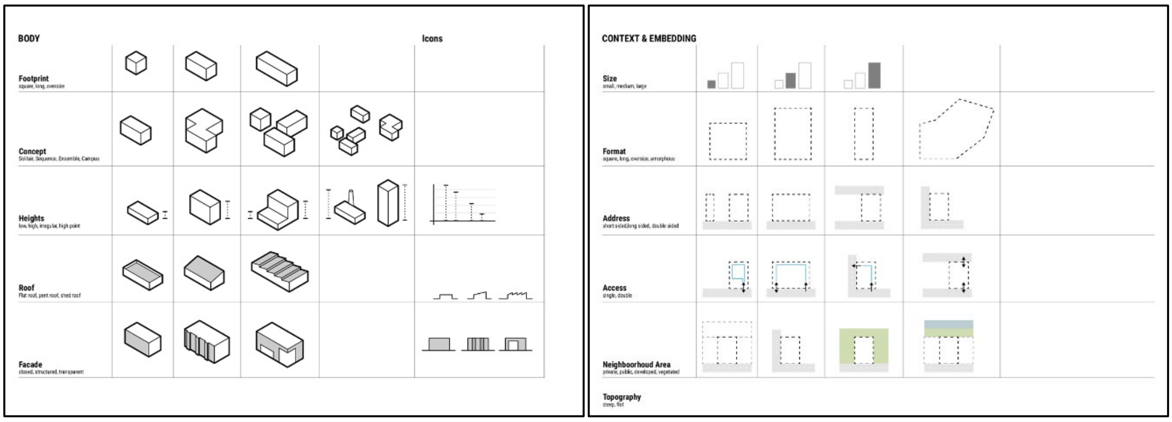

Figure 3. - 4. Possible Criteria for Catalogue by Alexandra Radounikli

Step 3 – Superposition and generating a scenario

Step three is the most experimental point in the methodology. In this step, a further use of the city is experimentally placed in direct structural contact with the production site. Step three aims to investigate a mixture of functions in a confined space and to discover direct neighbourhoods, and possible coexistences between production and other functions.

Step three takes the data from 1 and 2 and overlays a fictitious volume with production use and with one or more other urban uses. The overlay is done graphically and diagrammatically and will be evaluated using a SWOT analysis and the rating system from the second step. Step three represents a drawn scenario from which statements about city compatibility are to be made.

Applicability

A real spatial situation with real factors must be selected as the basis for testing a scenario. However, this does not diminish the universal applicability of the method. Rather, it enables the comprehensive consideration of additional factors. It should be emphasised that this application is a structural and spatial analysis that includes social factors as an extended level of consideration.

Within the scope of this work, thematic focal points and critical interfaces can be uncovered as a scientific basis for further investigations. Therefore, the lack of in-depth analyses is not an exclusion of relevance but is due to the limitation of the scope of the study.

EXPECTATIONS

The functional and spatial separation of industry from the other functions of the city has led to today's typical image of the commercial or industrial area of the city. Manifested through formal urban planning in the land use plan and thus part of legislation, this fundamental separation of functions is one of the biggest spatial hurdles to the sustainable integration of manufacturing industry into the urban fabric. Yet 'cities have always been places where trade and production, working and living were closely linked.'[25]

If we look at the goals for global sustainable development set out in the SDG, Goal 8: Economic growth and Goal 12: Sustainable consumption and production together with Goal 9: Industry, innovation and infrastructure and Goal 11: Sustainable cities and communities, they are linked in an interesting way.[26] Can steady economic growth be sustainable? And can industrial infrastructure in cities be integrated sustainably? Answers to these questions, among others, are to be found in this paper.

Instrument for Urban Planning

The urban processes that were once accelerated by uncontrolled economic growth have shaped the image of countless cities today. The aim of this study is to develop an instrument that can provide further options for future planning developments. A comprehensive catalogue of urban production forms and their urban conditions that can provide a guideline for the implementation of urban production in existing urban situations. An instrument that supports the consideration of all interests of all stakeholders in a mixed-use city scape.

CONCLUSIONS

The potential results of this investigation are yet to be seen, whether the combination of functions that have been separated for decades will lead to added value in urban life. The social and technical conditions are no longer the same. If the result of this work is that industrial production and manufacturing can be reintegrated into the urban space to realise the expected synergies in the urban economy and socio-economy, then the system developed will provide a supportive instrument for tackling the individual planning tasks.[27]

NOTES

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SPATIAL PLANNING WITH THE SUBSURFACE

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INTRODUCTION

The subsurface is a crucial basis for sustainable urban planning and therefore for the livability of cities.[1] It provides opportunities for geo-energy, vital soils contribute to CO_2-storage and water buffering, and healthy greening of cities is not possible without a vital soil. On the other hand, pollution, compaction, and fossil use threaten sustainable use of the subsurface. Strengthened by new policies – such as the European Healthy Soil Mission – new attention is given to role of the subsurface in urban planning.
This article focuses on the role of the subsurface in urban planning and how the subsurface can play its important role in this planning. It identifies barriers which for long have hindered the subsurface becoming an important part of urban and spatial planning. Barriers which find their basis in the tensions between the complexity of this subsurface system and the ordered use which regular urban planning asks from it. It sketches concrete possibilities, from actual cases, which the subsurface has to offer to urban planners. Finally, it aligns new strategies – based on a complexity-embracing approach - that can realize these possibilities in a spatial planning process.
In this article we use the term 'subsurface'. With this we address all there is beneath the surface (ground level) including soils, groundwater and deeper geological layers. In this, we go beyond formal definitions of soil, underground en subsurface, often used in geology and geography. We do this because this distinction is irrelevant for the issues addressed in the article and contra productive in a dialogue about spatial planning.
This article is based on design research in the Netherlands from 2018 on, lead by Saxion University of Applied Science. This research focuses on using mining activities for sustainable regional and urban development and redevelopment of brownfields. It will be illustrated by designs from students and professionals.

THREE CONCEPTS FOR SPATIAL PLANNING WITH THE SUBSURFACE

The subsurface makes an essential contribution to everything that is planned and built above ground. Not only does it provide raw materials such as sand and clay for construction projects, it is also used to build buildings upon and to construct sewers and pipes in it. It also provides us with energy, drinking water and storage of water and energy. The subsurface is essential for food production and contains two-thirds of all biodiversity on earth.[2]
Sustainable use of the subsurface for urbanization is proving difficult. Subsurface and spatial professionals live in different worlds with different languages. Subsurface and spatial planning have different time scales in which processes take place. Once overexploited or contaminated, the subsurface limits possibilities for above ground developments for decades. Interventions in the subsurface (such as

gas extraction) can induce earthquakes which only appear years or even decades later. This while changes above ground can be realized in a relatively short time and have an immediate impact on the subsurface. The invisibility of the subsurface is an additional barrier for connecting it to above-ground planning. Thus, the complex system of the subsurface poses harsh challenges for spatial planning in the Netherlands.[3]

Spatial planning can be seen as 'the coordination of policies and practices affecting spatial organization'. It can be regarded as a framework within which spatially relevant topics from different policy fields are considered, including mining, urbanization and climate adaptation.[4] Hajer et al. see spatial planning as 'an endless repetition of articulation and coordination'.[5] Articulation relates to developing a vision and adding questions, wishes and knowledge known. Coordination relates to making and fulfilling agreements between stakeholders and achieving results. This makes spatial planning by definition 'multi-interest' and 'multi-actor'.

Regular forms of spatial planning are less and less able to deal with the complexity of contemporary society and therefore hinder sustainable use of the subsurface.[6] To deal with this complexity additional forms of spatial planning have been developed. They are derived from several concepts. The concept of planning as persuasive storytelling[7] connects problems, relationships and processes in normative and descriptive stories about what the problem is and how it can be solved. Such stories are important means of propagating or disseminating a vision. The concept of planning as policy integration[8] involves both vertical (through all layers of one organization) and horizontal (by different organizations) policy integration. Policy integration is about striving to simultaneously achieve goals of multiple policy sectors. Policy integration can be stimulated by making better use of the opportunities offered by spatial planning to reach widely supported agreements on problems and solutions. To make policy integration successful, an overarching framework of sectoral policy fields is necessary. Spatial planning can provide that framework.[9] Another concept we can think of is the use of creative spatial design, at an early stage of planning.[10] Policymakers call such planning a '3D-spatial approach' and see it as a means of realizing the potential of the subsurface for different issues. It is here that the strength of design comes into play. Designers can connect and integrate different issues through design. Such concepts have led to explorative, interactive, visual multi-issue and multi-actor spatial planning approaches, in which 'design concepts' and 'windows of opportunities' are important triggers for progress.[11] For such a design process Doornbosch[12] developed six roles for the subsurface in spatial design, see figure 1. Four of these roles are functional: (1) an enabling role – providing space for networks, (2) a constructive role – to be able to build firmly, (3) a provident role – to provide energy for example, and (4) a conservation role –to preserve archaeological values for example. These roles facilitate the needs of people in the city – designers can work with them. Above this she added two intrinsic roles, which appear to be crucial for sustainable urbanization: (5) a natural role - guarding the intrinsic value of the natural system of water, soil and nature – and (6) an immaterial role - the intangible role concerning the intrinsic value of life with and on the subsurface, and the stories that the subsurface tells.

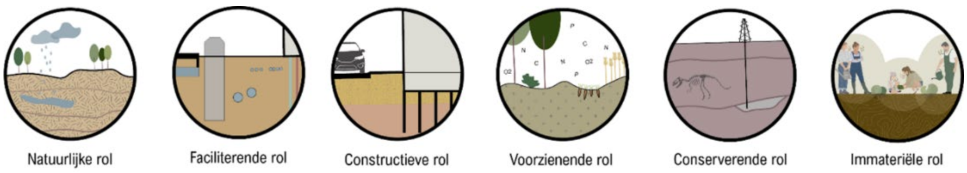

Figure 15. six roles of the subsurface in spatial planning and design (in dutch)[13]

The practical use of concepts like storytelling, policy integration and 3-D design for connecting above ground issues with subsurface potential, is yet scarcely researched.

METHOD

Sustainable use of the subsoil for urgent societal challenges asks for a spatial approach. As the use of the subsoil is interwoven in a complex system, it requires an explorative, narrative, multi-issue, multi-sectoral and design driven 3-D approach. How this is practically done, is yet much unknown. To anticipate on this, we work on two researches: the use of the subsoil in Twente and on the regeneration of brownfields for urgent spatial challenges in the Netherlands. In this we use a concept of design research with involvement of local stakeholders.[14] We use an interactive cyclic design and learning approach in which researchers, governments and companies in co-creation learned and developed insights together. The research started in 2018 and is still ongoing.

SUSTAINABLE USE OF THE DEEPER SUBSOIL IN TWENTE

Twente is a region in the east of the Netherlands. It has a specific geological structure, with gas reservoirs and salt layers in the deeper subsurface. Gas extraction has stopped, salt mining is still an ongoing activity in the region, leaving hundreds of so-called salt-caverns – existing and planned - in the subsurface of Twente at a depth of appr. 400-500 meters, see Figure 2. The research started with the following question: *'How can the use of the subsurface support a sustainable energy transition in the Twente-area in the Netherlands?'*. We investigated this in several spatial designs – developed by students and stakeholders. In one design the use of the concept of 'follies' was introduced for mining activities, see Figure 3.[15] These follies within the Twente landscape induce questions and dialogue between stakeholders about the use of the subsurface. And with that it raises awareness about their issues. In another design students worked on a multi-issue use of so-called 'salt-houses': houses used to mask the pumping installation where salt is extracted from the subsurface. The houses are designed as multi-purpose greenhouses for urban agriculture, see Figure 4.

Figure 16. location of existing salt caverns (appr. 400-500 m deep into the subsurface), in the Hengelo-Enschede area of Twente[16].

Figure 17: Design of follies at places with subsurface use in Twente, design by Nadine Rouwers.[17]

Figure 18. Salt-houses designed as multi-purpose greenhouses for urban agriculture, by students 'GreenSaltHouses'.[18]

From these individual, location specific, designs, spatial scenarios were developed in which a coherent use of multiple locations substantially contributes to the sustainable energy transition. For example, a scenario was developed in which salt caverns are used for the storage of sustainable energy from wind and sun. The caverns can thus provide an (inter)national energy hub in the Netherlands. This scenario is now developed into a more detailed scenario in which the spatial planning of generation (windmills, sun), storage (subsurface) and use (housing, industries) are integrally combined and designed.

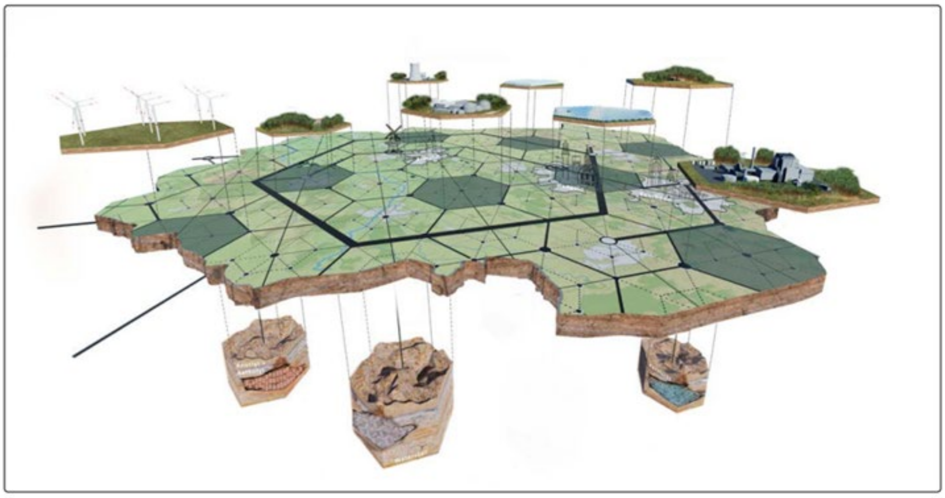

Figure 19. Design of a spatial scenario in which the use of salt caverns for storage of sustainable energy can provide an (inter)national energy hub in the Netherlands.[19]

BROWNFIELD REDEVELOPMENT IN THE NETHERLANDS

In the Netherlands an abundant number of locations contain soil pollutions which hinder spatial developments of these locations and their surroundings. Van de Griendt speaks of more than 600.000 locations.[20] At least up to 9.000 of them have a formal status as 'controlled' polluted area: the pollution is controlled by technical, geohydrological and administrative measures. These locations have an unused potential for urgent challenges which require space, such as housing, climate adaptation and the sustainable energy transition. The potential of these locations is estimated at a minimum of 6.000 ha, appr. 5 á 10% of the desired space for climate change, energy transition and urbanization in the Netherlands.[21] In research performed with several public and private partners this potential is researched: *'How can this potential be realized in a spatial development process?'.* In these, three perspectives are used: spatial potential, societal value and business development. This article focuses on the spatial potential perspective. We investigated the research question in several concrete spatial designs – developed by students and stakeholders.

In one case different kind of uses of an old rural dumpsite at Spankeren, east of Netherland, are explored. In one design 'off-grid living' for self-supported communities is explored, using energy-production from the underlying former waste-dump, Figure 6. In another design a more recreative approach is used, see Figure 7. Taking a more comprehensive design approach on these former dump sites makes it possible to add to regional challenges from a network of redesigned dump-locations, see Figure 8. Thus, the design approach looks beyond the specific locations. It uses the locations to look at broader issues, a network of locations and a regional perspective.

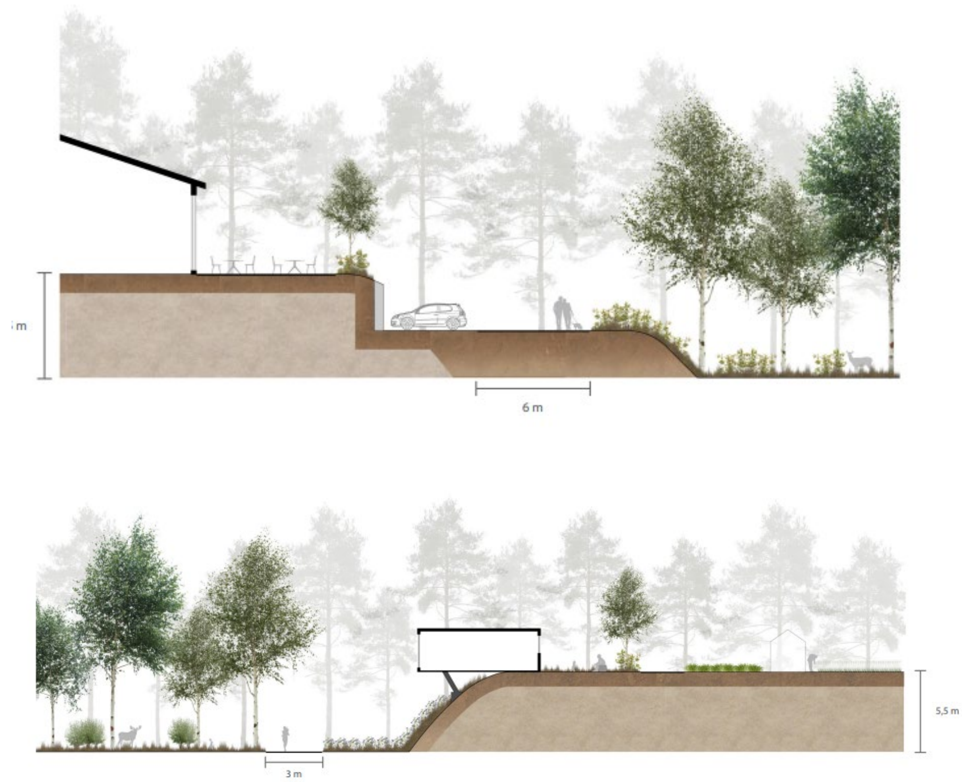

Figure 20. Off-grid living for self-supported living, using energy-production from the underlying former waste-dump.[22]

Figure 21. Recreative use of a former waste dump. Design of wooden cabin by architect Nicolas Dorval-Bory, Photo of wooden path in trees at Lend-a-Hand Trail, Twin mountain, White mountain national park, Bethlehem, New Hampshire, US.[23]

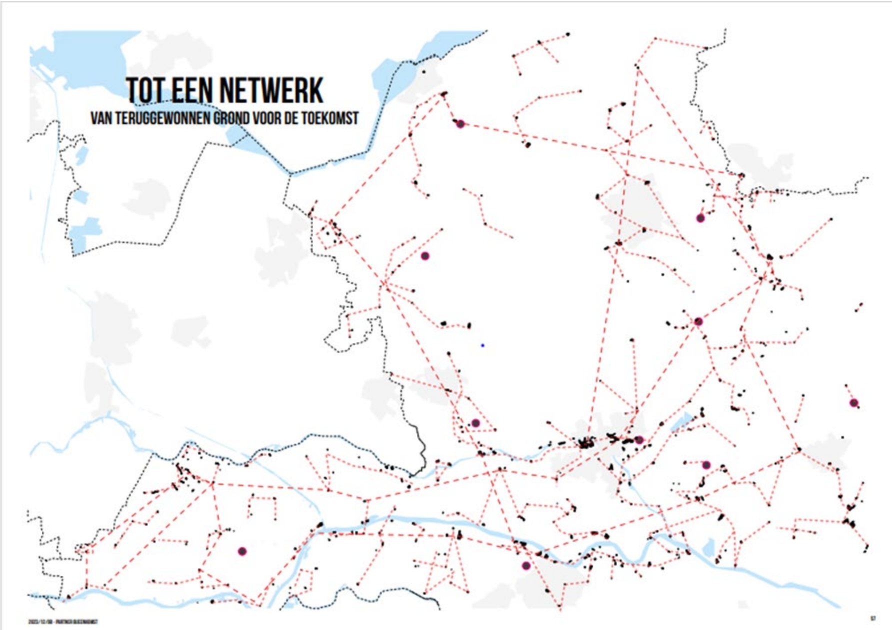

Figure 22. Network of former dumpsites with controlled pollution in the province of Gelderland, Netherlands. A network perspective can be used to design a substantial contribution to - for example – climate adaptation, recreation and/or sustainable energy production in the regio.[24]

CONCLUSION AND REFLECTION

The subsurface offers opportunities for developing healthy, climate proof, livable and sustainable urbanization. The designs shown in this article incorporate the subsurface as an integral part of the spatial design. They can be seen as examples in which an explorative approach with storytelling, policy integration and 3-D design, are used to connect the subsurface with above-ground issues. Although these designs are primarily location-based and explorative designs, a coherent broader approach of different subsurface locations (in both researches) show that its potential should also be captured from a more regional approach. In such an approach, different subsurface locations together can contribute to regional challenges. Such an approach asks for coherent regional spatial planning in which spatial issues and potential are connected. Thus, the spatial scale of planning and design with the subsurface is an important factor.

Within the designs in our research the subsurface is made 'visible and experienceable', for example by using follies or visual design of infrastructure for subsurface use. We call this 'exposing design' of subsurface interventions, in opposite of an 'assimilating' design, in which all subsurface interventions are made 'invisible'. We can conclude that using a broad 'exposing' design approach with multiple locations, helps to embed the subsurface in spatial development. Such approach should be based on the potential of the subsurface for spatial challenges, explored from different spatial scales. This raises new questions which are not yet addressed in our research. For example, the time scale of planning and design is not yet addressed. This is important because development of the subsurface takes time. In the case of salt caverns in Twente, development of new caverns takes decades. As well as the development of new energy infrastructure. Complying both to each other is a difficult planning challenge, with little experience yet. Furthermore, such planning asks for intensive cooperation between spatial planners and designers on the one hand, and soil professionals on the other. These are two worlds which have not yet worked intensively together. New ways of cooperation must be explored. And finally, planning with the subsurface asks not only for novel approaches and concepts, but also for concrete design principles and guidelines. A new field of knowledge within the world of spatial planning is thus developing.

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[23] by student group 'Stadslab 2023', Saxion University of Applied Science, 2023. Design of wooden cabin by architect Nicolas Dorval-Bory, http://www.nicolasdorvalbory.fr/project:treehouse/random:true. Photo of wooden path in trees at Lend-a-Hand Trail, Twin mountain, White mountain national park, Bethlehem, New Hampshire, US, https://spicebush.blogspot.com/2010/08/lend-hand.html.
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UNVEILING URBAN DESIGN THINKING DYNAMICS: PARTICIPATION FORMATS AND COMMUNICATION STRATEGIES IN EXPERIMENTAL URBAN POP-UP PROJECTS AND LIVING LABS TO FOSTER LIVABLE CITIES

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INTRODUCTION

Cities around the world are striving to become more livable, promoting healthy environments that support sustainability, inclusiveness, safety, resilience and high quality of life for people of all ages.[1] The necessary pace for transformation often stands in contrast to lengthy, bureaucratic planning processes, prompting the exploration of new approaches. This paper investigates the potential of experimentation rooted in designerly ways of thinking to transform urban planning and development. We analyzed two case studies in Munich, Germany - pop-up bike lanes and car-reduced neighborhoods - to explore how design thinking enhances urban experimentation. By comparing these two initiatives, we assess municipal engagement's inclusivity, transparency, and responsiveness, identifying key factors that influence citizen participation and the efficiency of experimental approaches in urban planning.

Theoretical Framework

Challenges in Contemporary Urban Planning

Driven by the goal of enhancing livability and facing challenges from the climate crisis and rapid urbanization, cities are under immense pressure to undergo swift and fundamental transformations.[2] To effectively address the complex and challenging issues in urban environments, sustainability serves as a crucial planning paradigm.[3] At the process level, however, traditional urban planning is considered outdated if it does not account for the dynamic, iterative nature of the design process. As Lerup quotes: “Traditional urban planning models are inadequate for addressing the fluid and unpredictable nature of contemporary urbanism.[4]

Tactical Urbanism, which emphasizes working with small-scale interventions and embracing flexibility, community engagement, and iterative processes, has gained momentum since the early 2010s. This approach, advanced by figures like Mike Lydon and Anthony Garcia and organizations such as The Street Plans Collaborative and Project for Public Spaces, focuses on "short-term action for long-term change" through quick, flexible, and scalable interventions.[5] Jane Jacobs’ emphasis on community-driven urbanism and small-scale interventions can be seen as precursors to this movement, and Jan Gehl’s work on human-centered urban design aligns with these principles.[6] Urban Living Labs (ULLs) and pop-up measures have emerged as methodological platforms that enable reflexive agency and engage various stakeholders in shaping the future.[7] ULLs involve users as co-creators, support a networked governance approach, and recognize government as an enabler of change.[8] Pop-up interventions that re-purpose sections of streets by reducing space for motorized traffic are intended to bring positive impacts, such as increased pedestrian traffic and more cycling, while being implemented quickly.[9]

Design theory that situates experiments and their significance and impact within a broader context of uncertainties can be found, for example, in Herbert Simon's 1969 book "The Sciences of the Artificial." He contrasts critical thinking, which deconstructs ideas, with design thinking, which builds them up. Simon defined design as "the transformation of existing conditions into preferred ones," a core principle of experimentation.[10] Design thinking is a human-centered approach to innovation and problem-solving that emphasizes empathy, ideation, prototyping, and testing to create user-centric solutions. It integrates creative and analytical processes to address complex challenges in a holistic manner.[11]

The necessity of a socio-ecological mobility transition is undisputed in the context of climate change, placing considerable pressure on municipalities to take action.[12] Hereby, as local key players, they are increasingly involving public participation in planning processes.[13] By integrating the public, they foster the co-evolution and co-specialization of knowledge and innovation paradigms, promoting a pluralistic and democratic approach that includes diverse societal needs and perspectives.[14]

The Design Thinking approach, ULLs, and pop-up interventions aim to effectively integrate participation while accelerating implementation. But how do these experiments fit into planning processes and municipal decision-making strategies? Under what conditions do such prototypes become effective and meaningful?

METHODOLOGY

This paper employs a qualitative research methodology, utilizing case studies to explore the effectiveness of urban experimentation. Data were collected through mixed-methods approach, a combination of interviews with key stakeholders, observations of the interventions, and analysis of relevant documents and reports. A total of 7 semi-structured interviews were conducted with administrative staff, 1 interview with the traffic commissioner of the largest city council faction, and notes from conversations with involved politicians who participated in site visits for Case B were prepared.

TWO CASE STUDIES FROM MUNICH, TRANSFORMING URBAN MOBILITY

After decades of efforts to shift away from post-war, car-centric urban planning, Munich adopted the urban development plan 'Perspektive München' in 1998.[15] It serves as a flexible framework to guide future urban development, with a core objective of fostering citizen participation. Specialized plans, such the traffic development plan, are part of it and are regularly revised: the current 'Mobility Strategy 2035' aims to enhance quality of life and the common good, targeting 80% emission-free vehicles, public transportation, and pedestrian or bicycle travel by 2025, along with achieving "Vision Zero" – no traffic fatalities.[16] While these strategies and plans establish the groundwork for a profound transformation at the planning level and garnered democratic approval through political endorsement, the slow and hesitant implementation of measures has been regularly criticized. As a result, a citizens' referendum 'Initiative Radentscheid' was initiated.[17] The referendum's objectives to strengthen cycling infrastructure over car traffic were adopted by the city council. However, the gap between stated goals and the actual transformation towards a sustainable, more livable city remained significant, not only in the cycling context.[18]

Case A: Munich's Pop-up bike lanes

Figure 23. Pop-up Bike Lane Elisenstrasse, Munich 2020; Photo: Florian Peljak

Background and implementation

During the Covid-19 pandemic, the Munich City Council approved the implementation of pop-up bike lanes to temporarily allocate more space to bicycle traffic at the expense of car lanes. The surge in bicycle traffic, evident from a 20 percent increase recorded in April 2020 compared to the previous year at the six permanent counting stations in Munich, prompted the initiation of the traffic experiment.[19] initiated by two party factions and approved by the city council based on a proposal prepared by the Planning and Building Administration. The strategy was to set up the pop-up bike lanes temporarily until the end of October 2020 and gather feedback to present to the city council in a new proposal, along with recommendations for further long-term actions. These temporary measures were implemented in the context of the COVID-19 pandemic, and the proposal explicitly stated that they 'do not constitute a preemption of future final solutions'.[20]
Located on five heavily trafficked streets, Elisenstraße, Theresienstraße, Gabelsbergerstraße, Zweibrückenstraße, and Rosenheimer Straße, the bike lanes were realized within several weeks after approval. Despite a contrary city council proposal from opposition parties and protests from cycling activists, the measures were reversed as planned at the beginning of November.[21] In the subsequent phase, the participation process was carried out to gather insights from public agencies and institutions, as well as to obtain the opinions of citizens. Based on this, the city council decided in March 2021 to permanently establish the bike lanes and had them implemented until May.[22]

Objectives and expected outcomes

The Covid pop-up bike lanes aimed to show how a transportation transistion can be implemented quickly and reversibly, avoiding premature, costly decisions. Permanent implementation would be decided after evaluating the measures and completing the participation process.

Participation and experimentation process

The experiment was politically initiated and administratively implemented, making it a "top-down" project from a process logic perspective. However, it aligned with the goals of the grassroots cycling initiative that gathered 160,000 citizen signatures during the referendum. The political and administrative actions thus reflected the public will. Traffic data, resident feedback, input from district committees, police, and public transportation were analyzed. Two digital public events, engaging around 500 citizens, were also held to discuss future implementations.[23] In addition, over 7,000 online questionnaires were analysed (n=7,117): almost 70% of the surveyed people were in favour of making pop-up bike lanes permanent.

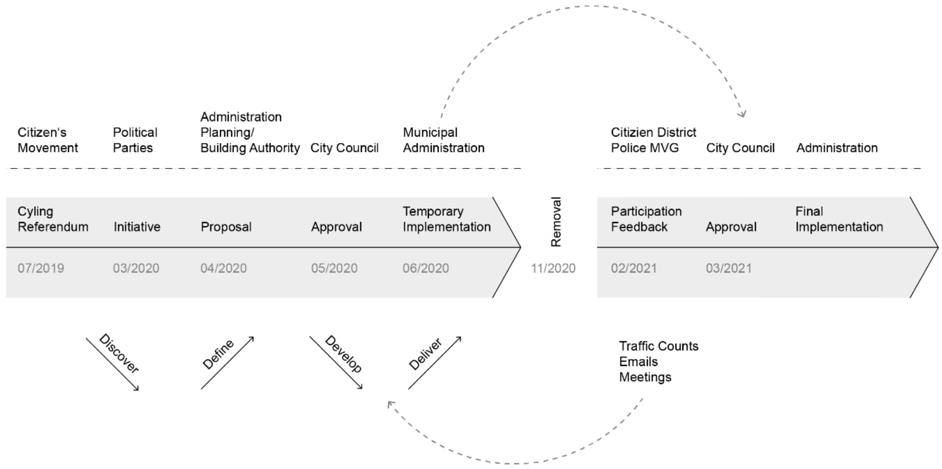

Figure 24. Case A: Framework for Testing and Iteration / Design Thinking Taxonomies.

Feedback gathering, information collection, and public participation occurred only after the removal of the pop-up bike lanes. This strategy enabled quick initial execution while ensuring transparency and participation during the testing phase before final decisions. The city's success in the 2021 Administrative Court case against an automobile club's lawsuit further demonstrates that the implementation strategy was both exemplary and legally sound.[24]

Case B: Living lab for a car reduced neighbourhood in Munich

Figure 3. aqt Living lab, Kolumbusstrasse, Munich 2023; Photo: Victoriya Zayika

Background and implementation

Munich aims to reduce motorized traffic by creating a largely car-free old town and transforming adjacent inner-city districts into low-traffic zones.[25] To test car reduction measures and foster livable neighbourhoods, the city co-initiated the car-reduced neighbourhoods project as part of the Munich Cluster for the Future of Mobility in Metropolitan Regions (MCube). Running from November 2021 to October 2024, the project is funded by the German Federal Ministry of Education and Research under the Clusters4Future Initiative. Led by the Technical University of Munich (TUM), the initiative involves a transdisciplinary consortium of academic, civic, and economic actors. TUM and the City of Munich, in close collaboration with local district committees, serve as the primary stakeholders and steering committee.

Two neighbourhoods were designated as real-world labs (RwLs) for testing car-reduction measures. The key site, Südliche Au, is a dense district connecting the Isar River meadows and slopes. Its demographics and mobility align with city averages, but high parking pressure and spatial inequality persist. Despite this, the area is well-served by public transport, with essential services reachable within a 5–10 minute walk.

After thorough investigations and an initial period of citizen participation, the street experiment temporarily repurposed approximately 100 parking spaces into open areas featuring urban gardening, grassy patches, a sand area, and seating options from June to October 2023. A road section was closed to through traffic, granting access only to pedestrians, cyclists, and emergency or service vehicles. Additionally, three mobility hubs were established, offering shared cars, bikes, and scooters. These measures, approved by the Munich City Council and the local district committee, were implemented by the Mobility Department.

Objectives and expected outcomes

The aqt project aimed to demonstrate how urban spaces can improve livability by addressing sustainability and social equity through innovative, community-led interventions. The RwL focused on implementation processes, including administrative approvals, planning, and citizen communication and participation, while collecting data on public acceptance and the measures' impact.[26]

Participation and experimentation process

Active resident involvement was central to the project, particularly among those directly affected. Approximately 8,000 households in the project area were invited to participate in surveys. Citizen consultations, co-creative workshops on urban gardening and future neighbourhood scenarios, and a diverse programme of activities facilitated public engagement. Key data were gathered through surveys conducted before (n=559) and after (n=924) the experimentation phase. The project drew significant media and public attention, sparking a nationwide debate on car-reduction measures in urban settings.

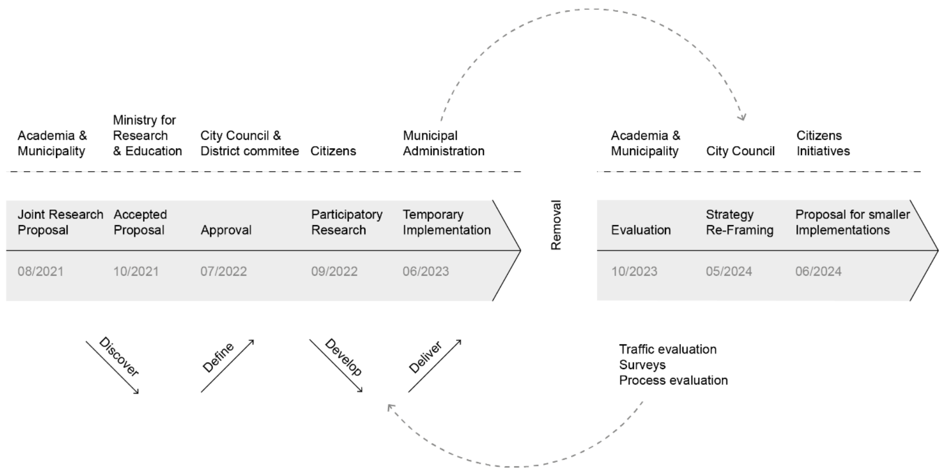

Figure 25. Case B: Framework for Testing and Iteration / Design Thinking Taxonomies.

As the project framework was designed by academia and city administration, Case B is characterised as a top-down initiative. The various application and approval phases reflect both the structure of research projects and the complexities of city governance, involving local committees (approval), city administration (ordinance), and the city council (consent). This hierarchical structure limited the

project's focus on citizen participation and co-design, which can only be fully realised in the further development of measures.
The dismantling of measures was planned from the outset, with long-term decisions at the city level to be made only after a detailed evaluation of research findings and experiences, expected to take approximately one year, has been completed. A lawsuit filed by three citizens resulted in a settlement, as municipal flexibility in such projects is constrained by the Road Traffic Regulations (StVO) and the Bavarian Road and Path Law. Despite this, citizen initiatives founded during the project continue to advocate for neighbourhood design, representing authentic bottom-up efforts beyond the project's conclusion.

COMPARISON OF THE TWO CASE STUDIES

The comparison reveals significant insights into the synergies and tensions between the roles of municipalities and the scope of citizen participation, summarized in Table 1.

Categories	Case Study A	Case Study B
Political Stakeholder	Clear guidance, constant political support	Involved from the beginning but faced inconsistent political support, leading to varying levels of commitment and challenges in implementation.
Administrative Stakeholder	High workload / pressure due to political directives (three city council proposals) and comprehensive participation process	Similarly high workload, with added complexity from political debates and media scrutiny. The controversy led to cautiousness in repeating or expanding the strategy.
Legal legitimacy	High pressure on the approving administration because of new approach and an unclear legal situation; Confirmation of the approach through a successful court ruling	Lack of an existing legal basis for conducting traffic experiments posed significant challenges. The court did not approve the approach, highlighting legal constraints.
Participation effectiveness	Above average participation: Online discussion > 500 people Online Survey n=7,117 Participants from across the city, not just local residents or neighboring business owners	Limited online participation due to personnel constraints. However, significant efforts were made through on-site consultations, workshops, two detailed online surveys, all indicating a high level of interest at the neighborhood level.
Individual and Societal Impact	Limited direct confrontation; High approval rate in the participation process; Discussions primarily taking place at an overarching level ('car versus bike')	Significant personal impact due to the transformation of parking lots, leading to unexpected and controversial media attention. Detailed surveys showed a majority positive opinion, contradicting media narratives.
Overall impact	Pop-up methodology was picked up and applied several times in Munich: Pop-up methodology is becoming the new normal	Initiated broader political discussions and revealed the need for new experimental administrative and legal processes. It acted as a catalyst for citizen initiatives

		and demonstrated tangible spatial impacts.

Table 1. Key Insights of Case Study A and B

Key Principles of Design Thinking

To explore synergies and tensions between municipal roles and citizen participation, we examine the application of design thinking in urban planning. In Case B, empathy was demonstrated through citizen consultations and co-creative workshops, providing valuable insights into local needs. However, incorporating these findings was slow due to bureaucratic processes requiring district committee approval and mobility department orders. In contrast, Case A's participation occurred post-prototype dismantling, entirely online due to the Covid pandemic. While digital formats reached a broader audience, including non-residents, they lacked immediacy in influencing interventions.

Ideation in both cases remained expert-driven, primarily involving urban planners and mobility enthusiasts. Administrative challenges were significant. Case A's pop-up process created high workloads due to formal requirements, including three city council proposals and elaborate citizen engagement formats. Despite achieving permanent implementation, the outcome was limited to 3 km of bike lanes. In Case B, legal uncertainties and political debates increased administrative burdens, leading to hesitance about future expansions.

Prototyping in both cases provided valuable real-world data and user feedback. In Case A, this informed long-term implementation, while Case B lacked a clearly defined long-term goal. While the urban development plan has goals and strategies, these appear politically fragile in the context of today's experiments. Political decision-makers closely monitor the progress of the experiments and express support or opposition depending on the outcomes. However, they do not defend the experiments as important tools for making informed decisions. Testing is the iterative process of evaluating prototypes, gathering feedback, and making necessary adjustments. This stage is crucial for ensuring that the final solutions are effective and well-received by the community. No further iterations were planned for Case B after the measures' removal, shifting responsibility to citizen initiatives.

Temporary interventions in both cases demonstrated potential for lasting change but highlighted limitations when Design Thinking principles were inconsistently applied. Effective integration of citizen participation requires experiments to adhere to clear, long-term goals and maintain reversibility and cost-efficiency during prototyping. However, deviations arise due to political concerns (negative press or voter backlash), administrative fears (mistakes or liability), and citizen dissatisfaction (perceived exclusion). These disruptions interrupt the iterative logic of Design Thinking, which thrives on testing constructed realities rather than preemptive approval.

Lydon and Garcia highlight that "The goal is to show people different opportunities in the real world so that more informed decisions may be made by a more diverse audience of people."[27]

Properly executed experiments serve as powerful tools for community engagement and data-driven decision-making. Reflecting Donald Schön's concept of design as a "reflective conversation with the situation," experimentation effectively adapts to real-world challenges.[28,]

RECOMMENDATIONS

The Munich case studies highlight the importance of adhering to key principles for urban experiments to drive the transformation of livable cities. Experiments bring concepts to life, make assumptions visible, and enable stakeholders to experience changed realities. Fostering an experimental mindset at all levels, embracing positive feedback, and learning from errors are essential. Knowledge sharing and careful selection of participation formats further enhance the process.

Effective urban experimentation requires:

1. **Clearly Defined Goals**: Align objectives with broader urban planning and sustainability frameworks.
2. **Supportive Policy Environment**: Develop flexible policy frameworks to encourage innovative urban experiments.
3. **Rapid Implementation and Iteration**: Focus on quick execution and iterative testing with temporary measures.
4. **Inclusive Participation**: Engage a diverse range of stakeholders through carefully selected participation formats.
5. **Transparent Communication**: Maintain clear communication with stakeholders, regularly updating them on progress.
6. **Experimental Mindset**: Foster a culture that values innovation, embraces learning from failures, and supports iterative development.
7. **Positive Feedback and Error Culture**: View feedback and errors as opportunities for improvement.
8. **Knowledge Sharing and Collaboration**: Promote collaboration among stakeholders to leverage diverse expertise.
9. **Evidence-Based Decision Making**: Base decisions on empirical data gathered during experimentation.

CONCLUSION

Effective urban experimentation hinges on clearly defined goals, a supportive policy environment, rapid implementation, and an experimental mindset. Adhering to these principles enables cities to foster inclusive citizen participation and accelerate the transition toward more livable and sustainable urban spaces. Prototypes, as tangible and visible interventions, democratise participation by engaging a broader audience, including those often excluded from conventional processes. The case studies underscore the potential of experimental approaches while highlighting persistent resistance among some stakeholders to dynamic and agile planning methods. To overcome these challenges, urban planning must embrace iterative, adaptive processes that can effectively address complex, evolving urban needs. Future research should prioritise evaluating the long-term effects of experimental urban living labs, including their social, political, and environmental impacts. Comparative studies across diverse cities and contexts will be crucial in identifying transferable best practices, refining methodologies, and enhancing the transformative potential of urban experiments.

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QUALITATIVE EVOLUTIONARY DESIGN FOR SOCIAL INNOVATION IN ARCHITECTURE

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INTRODUCTION

Following the biological idea of changes in populations over successive generations, evolutionary design uses defined principles to generate and refine design solutions that meet specific criteria. The term "evolution" originated from biology and natural history. It refers to changes in the characteristics of biological populations over generations. Living species develop fitness traits that help better adapt to their environment.

Applying evolutionary methods to architecture is challenging because of the qualitative nature of the field. The experimental part of this research mobilised students in Aalto University's Urban Design and Planning Capstone Project in 2023 to test a method of qualitative evolutionary design to produce socially innovative designs for sites in Finland and UK. The results indicate that there are three meaningful purposes that are suitable for qualitative evolutionary development in architecture: 1) building and block types, 2) targeted qualities, and 3) site-specific features.

EVOLUTIONARY DESIGN

Evolutionary design is a methodological approach that allows growing an entity in a natural way, based on varying and optimising design solutions.[1] Like biological evolution, it is established on the principles or mutation, combination, evolutionary reasoning, selection, and the refinement of solutions.

Evolutionary design allows designers such as architects to use defined principles to generate, refine and optimize design solutions that meet specific criteria. These points of reference can be for example physical, sociological, cultural, or economic. An important feature in such a process is that components can be freely substituted to improve the design, modify performance, and change features.

Evolutionary design responds to the complexity of a context by simple, flexible and self-organising design recipes. The approach is iterative and incremental. Therefore, one of the main benefits of evolutionary design is that based on a robust design made by minimum effort, it can help designers to overcome the limitations of their own creativity and experience by allowing also other agents to develop their design further. As an example, the first aeroplane by Wright brothers was very robust compared to contemporary fighter planes. Crowdsourcing is another example of evolutionary design, where an initial idea or a rudimental sketch becomes developed by many volunteers.

Architecture

In architecture, evolution can thus mean keeping a primitive architectural concept and developing the features of the design measured against defined criteria. For example, Christopher Alexander's book A Pattern Language introduced this type of a methodology that uses a set of design patterns or rules that can be refined over time to create buildings or spaces that are well-suited to the needs and preferences defined by Alexander.

Evolutionary design methods have this far been used mostly in quantitative projects, for example in software development and computational architecture. Software and applications can start their life in a simple form and later became more sophisticated through an evolutionary process. In quantitative evolutionary design, a parameter can be anything numerically calculable from designing a building that maximises natural light[2] to creating a CO2 neutral urban block. A quantitative approach is fitting to technical characteristics, engineering, or such design theory, where the design process is mechanical problem-solving activity, and the goal is to create a solution that meets specific numerical criteria or objectives. However, goals and parameters also in computational evolutionary design or in user-based design theory require better and more varied definition than technical performance and efficiency.

Evolutionary design has also been used to produce design alternatives that are optimised for multiple criteria. This is a very common situation in architecture and multi-objective optimisation can be difficult when applying traditional design methods.

Applying evolutionary methods to architecture is challenging because of the qualitative nature of the field of architecture. There are limitations in explaining architecture properly in terms of quantitative goal setting, constraints and rules. In the case of architecture that surpasses technique, a goal setting should be something else than quantities or purely technical problem solving. A design process in architecture is only very partially and poorly explained in terms of quantitative motivation, control and rules. The skill of a professional in architecture is rather expressed in the actual framing of the problem to be addressed.[3] Ideally, evolutionary design in architecture could thus help to generate also qualitatively optimised and creative design solutions. Examples for such areas of qualitative design parameters in architecture could include qualities related to such vague entities as place, time, movement, change, type, and value.

Because architecture is always situated in an open social environment with contrasting interests, it spreads a plurality of cultural effects, depending on relationally defined, varying definitions of value. Its evaluation is based on social standards on what is acceptable and what not; as well as on what produces social prestige in its context. The designer needs to answer, whose values and whose benefits to support. Is there short-term or long-term value created? From a value-related and experiential viewpoint, such qualitative topics define architecture as the programming of use, mixing of user groups, types of urbanism, rarity, feeling, behaviour, attitude, expression, meaning, attraction, image, identity and priorities. These sociologically inclined attributes become materialised in architectural imagination through e.g., 1) the selection of locations and the utilisation of existing spaces, 2) deciding on how natural seasons become taken into account, 3) the quality of spatial succession, 4) the creativity of spatial and event programming, 5) the development of building and block typologies, 6) the creation of intentional feelings such as the dramaturgy of excitement and relaxation, atmospheres, multi-sensory experiences, 7) interconnectedness and interactions, 8) uniqueness, 9) the interplay of diverse value systems and 10) the critical capacity of design. The development of architectural components, and experiences created by architecture, relate to many qualitative parameters like these. The focus in the scrutiny at hand lies especially on the possibility to pursue social innovation through architectural creativity.

SOCIAL INNOVATION

Evolutionary design produced by humans is sustainable if we believe Currie et al. when they write that integrating evolutionary theory and research on socio-economical systems can lead to a better understanding of changes in those systems and positive interventions for a more sustainable Anthropocene.[4] The aim to understand and interpret complex social phenomena and challenges is the rationale behind not only quantitative evolutionary design, but also social innovation, which addresses social challenges.[5] Societal innovation is, for example, needed for sustainable development, in which environmental protection and societal value are internalized instead of externalized. Equality, justice, empowerment, poverty, resilience and conflicts are typical questions for social innovation.[6]

Combining the definitions by Encyclopedia of Social Innovation,[7] OECD,[8] and European Commission,[9] ideas belonging to social innovation can increase such targets as efficiency and productivity in an organisation, advance social security, improve welfare, wellbeing and resilience of individuals and communities and enhance social relationships as well as support new collaborations. What is not social innovation is innovations without positive social change and social entrepreneurship, where specific positive societal effects have been articulated and the pathways to achieve these effects have been identified.[10]

Social innovation and architecture

Social innovation in architecture can take place through, for example, creative spatial programming, settings enabling sustainable lifestyles, trans-disciplinary collaboration projects, urban regeneration, adaptive reuse, placemaking, and high-quality affordable housing. Examples of social innovation from the history of architecture include, amongst others, 1) Ancient Greek agoras, which were exemptions in the generic serial reproduction of the urban tissue, and where the social benefit was their ability to produce social cohesion, to support spirituality, religion, administration and orientation, 2) Ancient Roman cities, where life takes place on public spaces, 3) the medieval urban street layouts and piazzas dedicated to commerce and civic events, 4) ideal industrial communities such as Fourier's 19th century Familestère, integrating housing and community services, 5) Team Ten's 1960's shift in urban design from functionalist separated uses to dynamic mixes and overlapping territories, urban webs and superblocks, emphasising human scale, networks, compactness and intimacy, 6) Archigram's 1960's combination of architecture and pop culture and the integration of urban happenings and new ways of living, 7) 1980's and 90's programmatic mix, and the striated city by Rem Koolhaas, enhancing pluralism, contrasts, experience and positive congestion, 8) 1990's hybrid combinations of housing and community services, interdisciplinarity and openness by transparency, 9) 2000's diagram-based design for condensing ideas about heterogeneity; liveability, walkability; the sustainable high-tech cities, mediatheques, urban ecosystems, fusions of building and landscape, urban regeneration concepts, strategies for non-programmed spaces, as well as designing degrees of informality in architecture and liveability. All these implemented concepts could be called examples of social innovations in the history of architecture.

Social innovation in architecture could mean today, for example, tools for sustainable ways of living, adaptive reuse, or transdisciplinary collaborations to answer sustainable challenges.[11] The social challenges which we examine in this scrutiny presented are related to community retrofit – how to improve existing urban places for better qualitative performance – making additive changes in an existing environment through an upgrade. A newly defined qualitative evolutionary method was used in this pursuit.

EXPERIMENTS AND QUALITATIVE EVOLUTIONARY METHOD

Students in Aalto University's course of Urban Design and Planning Capstone Project (2023) were asked to follow steps for qualitative evolutionary design and produce designs with social innovation for two sites: Tervasaari Island in Helsinki, Finland, and Ethelburga Estate in London, UK. This project was a collaboration with Royal College of Art in London and Shibaura Institute of Technology in Tokyo. Altogether 23 students, six teachers and three researchers participated this endeavour. It was emphasised to the students that it is not enough to design purely functional artefacts, but especially social innovation and simultaneously 1) support significantly higher societal goals through creative work without compromising the quality of architecture, and 2) to facilitate evolutionary, place-based experiences that support sustainable, long-term life-cycle development.

Our method, which is described in the next chapter, is based on dividing the design into manipulable parts – "modules" (that could also be called a "pattern"), – which can evolve in an asynchronous manner. Modular design states that a product is made of subsystems that are joined together to create a full product.[12] The built environment can in this way be divided into components with different life cycles.

Design method

These were their steps for qualitative evolutionary design:

1. Define the input. This means deciding on the "module" whose performance will be measured, including its extents and type. This structure of division may be a new way to comprehend environment consisting of patterns (combinations of spaces and/or volumes, and their use) and allow the non-synchronised development of these. For example, a city block or a building can be divided into unconventional parts that can evolve in their own pace without integrated control – such as an entrance, roof-scape, or ground floor spaces combined. This type of thinking is rather new for building architecture and urban design and planning, where it has traditionally been the totality which is supposed to be the key unit of development – *Gesamtkunstwerk* – and not its allochronic components.

A module in our task could be a whole area, a block, a public space, a street, parking places, urban squares, ground level spaces of blocks, the roof-scape, entrances, or alike. This can be a combination of traditional components of architecture or new ones in an unorthodox manner (e.g., addressing all garbage sheds of the area at the same time).

2. Select your qualitative topic. This could also be called the parameter, or the characteristic goal. Start by clearly defining the qualitative goal you want to.

3. Research how the success of your specific goal – its "fitness measure criteria" has been evaluated earlier and elsewhere. Use internet and literature in this sub-task to understand which have usually been the criteria for evaluating how successful your solution for the input is. Don't worry if the criteria appear obscure or confusing – this "sweatiness" is typical for qualitative criteria.

4. Decide on your own measurement technique. Dictate the qualitative criteria that will be used to evaluate the quality of each design solution within your selected module and topic. Decide on how you are going to evaluate the success of your designs, based on the information from the previous stage and your assessment of that. This step requires turning the qualitative criteria into quantitative data in a creative way.

5. Generate an initial "population" of design alternatives – a set of different quick designs. These design solutions should be diverse and cover a wide range of possible directions. This forms the initial "rough sketch" – components and alternatives, with which the system is allowed to only barely work by answering to the fitness measurement criteria but is not necessarily yet much developed. Using generative AI imaging tools (Dall-e, Midjourney etc.) is used in this stage and in the following steps.

6. Measure the fitness of your sketches (population) against your success parameters and select the best ones for further development.
7. Morphogenesis and variability: Apply evolutionary “operators” such as mutation, recombination, and selection, to generate new design variations from the initial selections based on your fitness criterium.
8. Repeat the process. Continue to generate new, evolved design solutions and estimate their fitness until the “best solution” has been identified.
9. Refine the solution. Once the winning solution has been identified, refine that further to improve its performance or address any potential challenges.
The outcome by the students was short videos presenting their work and the evolutionary process behind it in a narrative manner. The following images are excerpts from these videos.

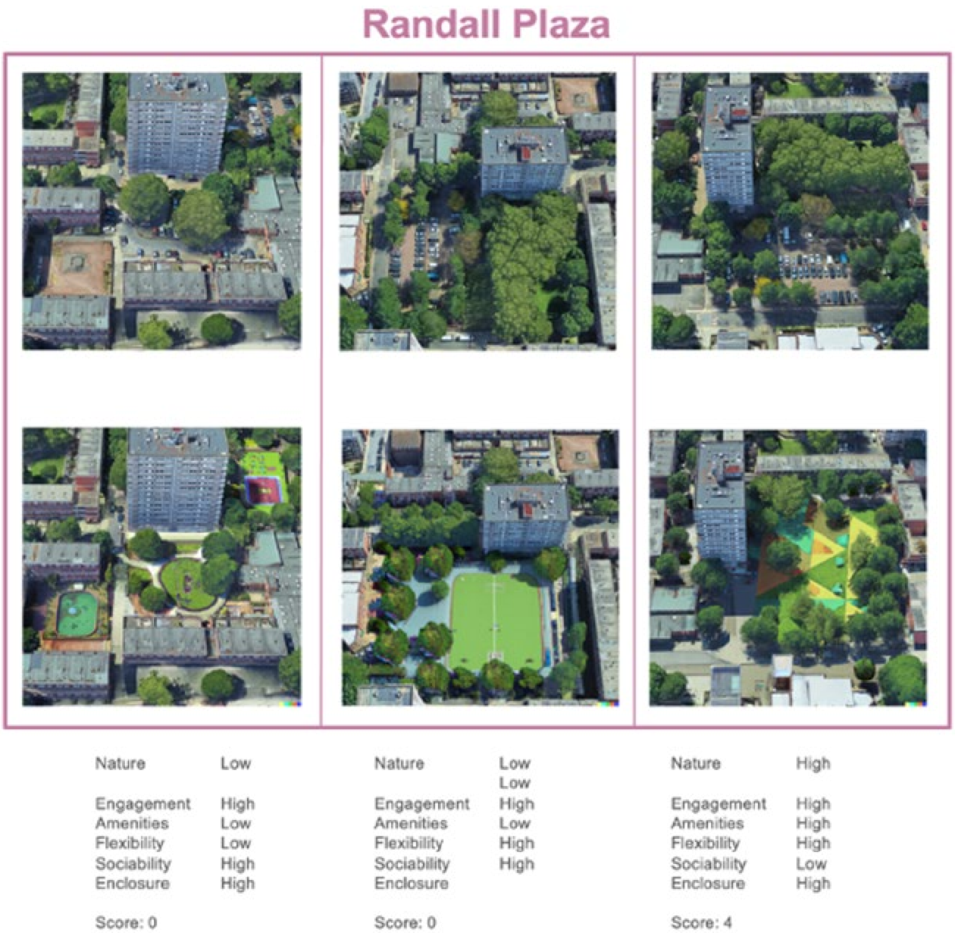


Figure 1. A set of plazas in Ethelburga with the quality “interconnectedness” with original photos on top row and AI (Dall-e) generated population below with scoring by Cian Evers.

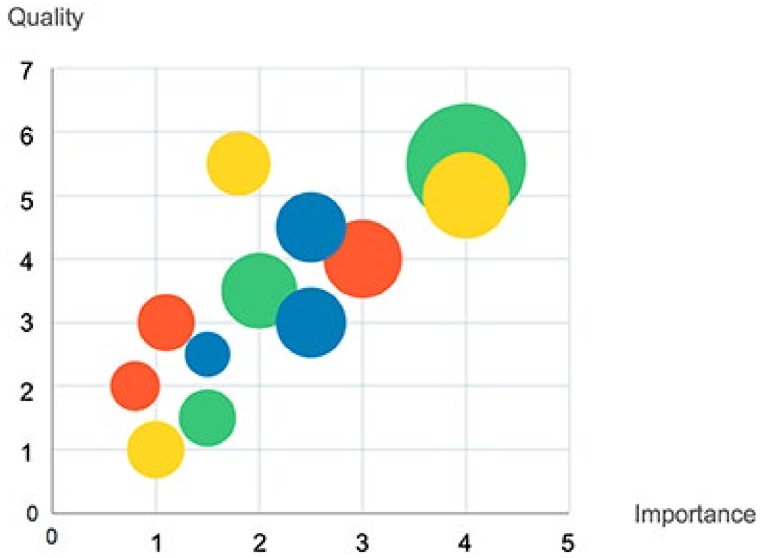


Figure 2. A graph presentation for the evaluation of several sites within the design area by Cian Evers.

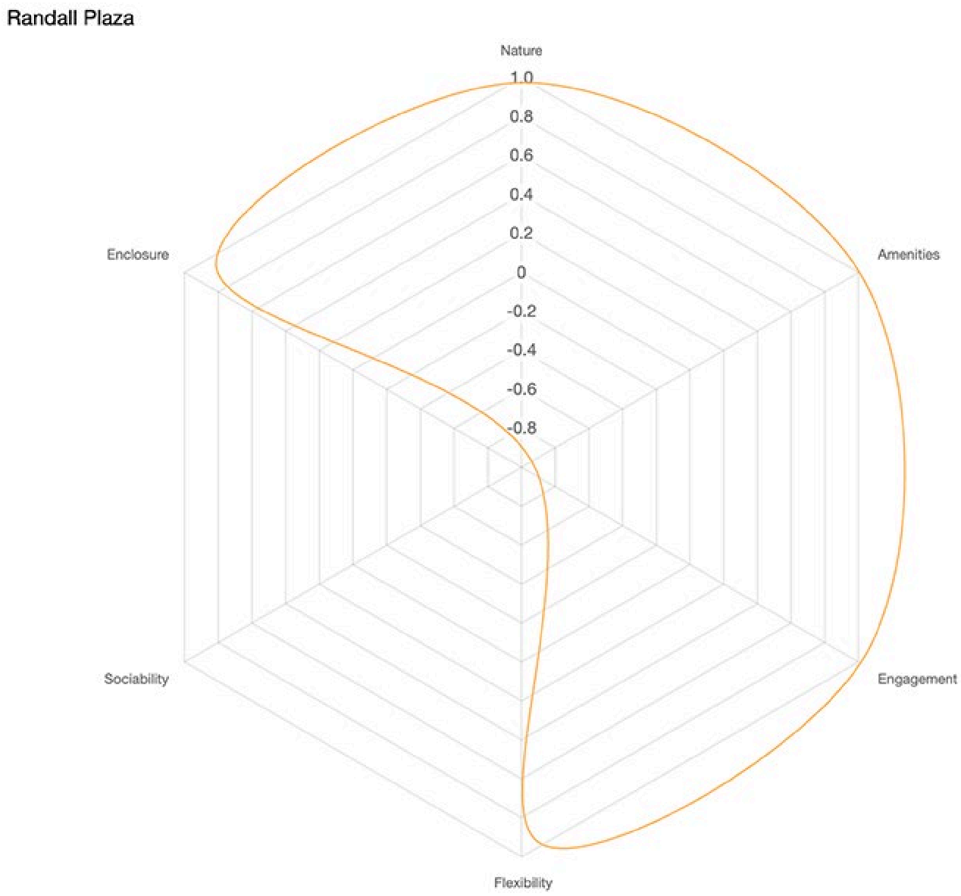


Figure 3. A graph for the evaluation of the interconnectedness of an individual site by Cian Evers.

Communal yard with round and soft furniture, stimulating play areas for children, chess playing elderly, mothers gardening, exhibition spaces, students painting on asphalt. London, Battersea. Background traditional english townhouses with new housing on top.

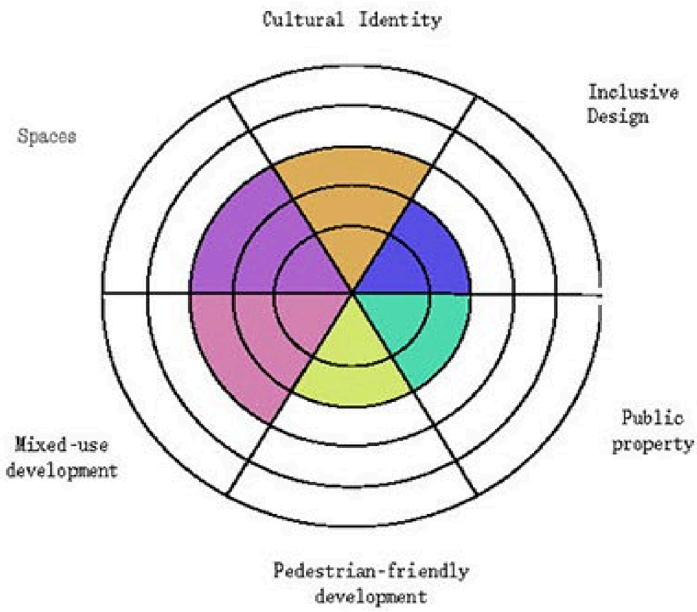


Figure 4. A sample from a population of AI-assisted design alternatives with its prompt aiming to increase "communality" and a graph for evaluation by Eeva Rosenqvist.

Figure 5. Integrated design featuring the variability and localization of the parameter of communality by Eeva Rosenqvist. This project was about the urban retrofit of Ethelburga Estate in Battersea, London.

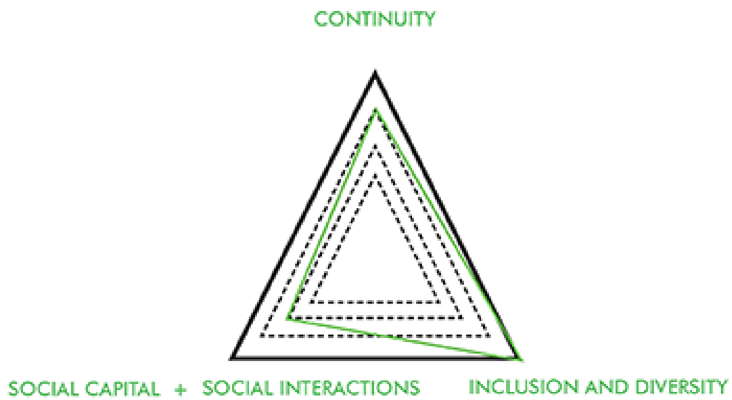
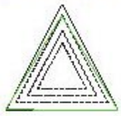


Figure 6. Liina Kiviö's graph purposed to measure constituents of social dynamics and interactions.

MULTIGENERATIONAL PARKS

Families and friends gathering in urban parks for picnics, playing games, or simply socializing.

Prompt:A multi-generational park with spaces for children to play and adults to exercise or socialize, different kinds of materials, the benches and kids play equpments have round edges, accessible with a wheelchair, gardening activity, elderly people exercising, photorealistic, England
AI: Bing Image Creator (Developed by DALLE)

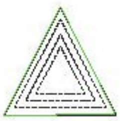


=11

Prompt: A park with spaces for children to play and adults to exercise or socialize, different kinds of materials, colourful flowers, round edges, accessible with a wheelchair, gardening activity, a yoga class for the elderly
AI: Bing Image Creator (Developed by DALLE)

=9

Prompt: a park with spaces for free play, furniture with soft edges, lots of benches, safe and comfortable outside toilets, green herbs for growing plants, outside training gym for adults
AI: Bing Image Creator (Developed by DALLE)



=12

Figure 7. Liina Kiviö's evaluations of design alternatives generated by AI.

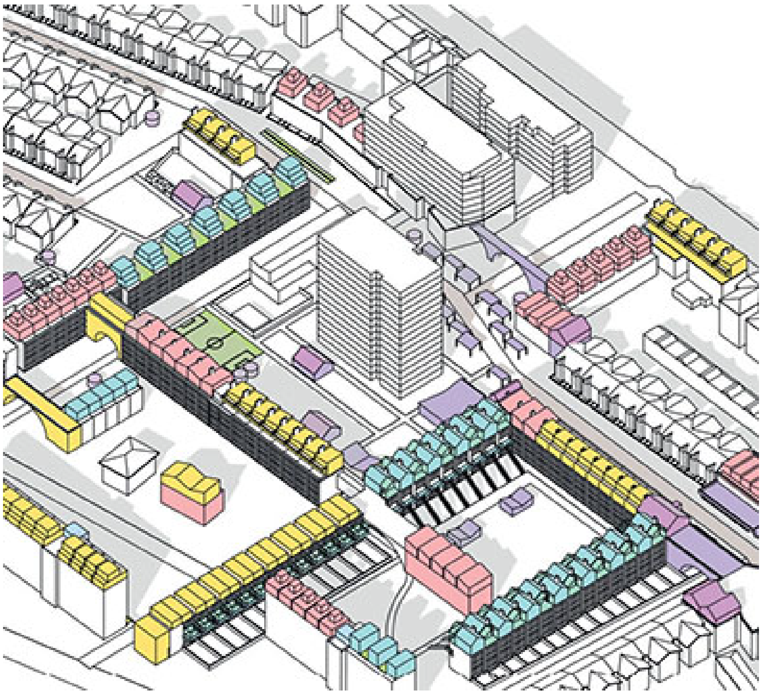


Figure 8. Enlargement of the middle part of Liina Kiviö's integrative plan for Ethelburga based on evolutionary success parameters regarding social dynamics and interactions.

CONCLUSION

It was not possible to categorise meaningfully different useful types of evolutionary design in an urban setting before these concrete design works were produced. Their evidence pointed out that there are three different types of evolutions in architecture, where evolutionary development is useful: 1) types – the evolution of building and block types, 2) missions – qualities such as communality, which can be developed through evolutionary steps, 3) sites – locations of architecture have their own evolving legacy with already existing contextual characteristics. All of these trajectories can be developed in an evolutionary manner. However, the nature of architecture as multi-criteria optimisation of specific projects complicates the assisted evolutions.

Some tactics for evolving types include hybrid development (combinations of types), manipulations of the demarcation of private, semi-private and public spaces, and changes of dimensioning, allowing new and mixed uses. Evolutionary missions require ranges of measurement criteria, and in this case, they were based on presently available research data. The more there were simultaneous qualitative criteria, the more difficult it became to imagine design solutions. The idea of an evolution of a site assumes on its stable identity – it's spirit or defining characteristics, which raises the questions of power and legitimacy in defining these essential properties.

Generative AI visualisation tools proved to be a practical way to generate prototypes and population. The graphic representation (diagrams and charts) of qualitative evaluation proved to be crucial in the process.

NOTES

[1] Philip Steadman, *The Evolution of Designs: Biological analogy in architecture and the applied arts* (Cambridge: Cambridge University Press, 1979), 71-152.
[2] This is where the architecture office MVRDV, for example, has been a pioneer.
[3] Horst W. J. Rittel and Melvin M. Webber, "Dilemmas in a general theory of planning," *Policy Sciences,* vol 4 (1973): 155-169,
https://urbanpolicy.net/wp-content/uploads/2012/11/Rittel+Webber_1973_PolicySciences4-2.pdf.
[4] Thomas E. Currie et al., "Integrating evolutionary theory and social–ecological systems research to address the sustainability challenges of the Anthropocene," *Philos Trans R Soc Lond B Biol Sci,* (January 2024), doi: 10.1098/rstb.2022.0262.
[5] Jane Alice Sánchez-Cruzado Ryan and Andrés Araujo De La Mata, "What is the best way of implementing social innovation?," *Social Innovations Journal,* vol. 10 (2021),
https://socialinnovationsjournal.com/index.php/sij/article/download/1445/1574/6107&ved=2ahUKEwjM5a6r4eSHAxX0BxAIHd6GF5wQFnoECBMQAQ&usg=AOvVaw3jGGqa4MyvqRW7riOGnzW8.
[6] Henk B. Diepenmaat, René Kemp and Myrthe Velter, "Why Sustainable Development Requires Societal Innovation and Cannot Be Achieved Without This," *Sustainability* 12 (2020), doi: 10.3390/su12031270.
[7] Jürgen Howaldt and Christoph Kaletka, eds., *Encyclopedia of Social Innovation* (Dortmund: TU Dortmund, 2023).
[8] OECD, *Recommendation of the Council on the Social and Solidarity Economy and Social Innovation* (Paris: OECD, 2024), accessed August 8, 2024. https://one.oecd.org/document/C/MIN(2022)14/FINAL/en/pdf.
[9] European Union, *This is European Social Innovation* (Brussels: European Union, 2020).
[10] José Alberto Solis-Navarrete, Saray Bucio-Mendoza and Jaime Paneque-Gálvez, "What is not social innovation," *Technological Forecasting and Social Change* no. 1 (2021), doi: 10.1016/j.techfore.2021.121190; Nadine Hietschold et al., "Pathways to social value and social change: an integrative review of the social entrepreneurship literature," *International Journal of Management Reviews*, 25(3) (2022): 564-586,
doi: 10.1098/rstb.2022.02620.1111/ijmr.12321.
[11] Donagh Horgan and Branka Dimitrijević, "Social Innovation in the Built Environment: The Challenges Presented by the Politics of Space," *Urban Science* 5, no. 1 (2021), doi: 10.3390/urbansci5010001; Ezio Manzini, "Social Innovation and Design: Enabling, Replicating and Synergizing," *Changing Paradigms: Designing for a Sustainable Future* (Helsinki: Aalto University School of Arts, Design and Architecture, 2015), 336-345; Sasha Tsenkova, "Design Thinking and Social Innovation in Planning Education," *Edulearn Proceedings* 23 (Valencia: IATED Academy, 2023), 8065-8072. doi: 10.21125/edulearn.2023.2091; Marianna Marchesi and Chris Tweed, "Social innovation for a circular economy in social housing," *Sustainable Cities and Society* 71 (2021), doi: 10.1016/j.scs.2021.102925; Marialuce Stanganelli et al., "Adaptive reuse of abandoned urban assets for cultural and social innovative development," *Resilient and Sustainable Cities* (Amsterdam: Elsevier, 2023), 569-603. doi: 10.3390/su13105531.
[12] Karl Ulrich, "The role of product architecture in the manufacturing firm," *Res Policy* 24(3) (1995): 419–44, doi: 10.1016/0048-7333(94)00775-3.

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TRANSFORMING OPEN MARKET. LOCAL KNOWLEDGE AND GLOBAL RISK IN CATANIA'S (ITALY) HISTORIC FISH MARKET

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INTRODUCTION

Urban contexts are traversed daily by multiple conflicts and interconnections between local and global phenomena in which scaling, rescaling and interdependence processes emerge.[1] The planetary configuration of urban life,[2] thus the overall extension of the urban over the entire globe, shows a series of new and decidedly contradictory phenomena concerning the traditional development model of large cities.[3] The succession of urban explosion and contraction phases do not represent an absolute datum but constitute processes produced by specific political and economic relations, thus subject to contestation and malleability.

The disastrous impact of climate change on urban contexts has encouraged the need to reduce the degree of exposure to disaster risks to reduce mortality economic and physical damage. The adoption of the Hyogo Framework for Action between 2005 and 2015 represented the introduction of resilience as a central reference for building models capable of reducing and addressing risks internationally. The subsequent Sendai Framework for Action (2015-2030) highlighted the policy orientation for building resilient communities, declining the concept of resilience into a specific social group's capacities to respond to external disruptions resulting from social, political and environmental changes. Social resilience could be understood as building these capacities before or after a disaster, enabling the 'community' to cope with the event's outcomes and return to the pre-disaster situation.[4] In the chaos generated by disaster events, it seems necessary to emphasize that if resilience is the capacity of a community or society to recover, then we have forgotten that human practices and determined systems produce disasters.[5]

This paper proposes an analysis of ethnographic data collected between 2022 and 2024 through interviews, participant observation and participatory mapping of spaces in the context of the historical market in Catania in Sicily (Italy). This research analyzes how global risks relate to developing and sharing local knowledge concerning urban spaces and their specific spatial practices. This study demonstrates how local knowledge is developed through the daily experience of inhabitants and market workers and how valorization and circulation can represent resources to make our cities increasingly liveable, reversing the relationship between global phenomena and local life forms.

Resilience cannot be considered a concept based on measurement indices but rather a process based on social contradictions and the everyday practices of people living in a context. Space is always a limited resource, and various limitations (legal, cultural, environmental, and so on) affect its appropriation and

symbolization.[6] One of the most effective ways to investigate forms of opposition and contestation concerns the social construction of space.[7]
The historical market called "Pescheria" (Fisher market) in the city of Catania (Sicily-Italy) constitutes the confluence of social, spatial and economic processes in which operators, buyers and citizens act in everyday life, sharing and promoting forms of local knowledge. The case of the Catania fish market reflects the central aspects of the frictions concerning global interconnections between cultural diversities that reproduce inequalities, instability and creativity.[8]
Ethnographic research in the market context sought to analyze the relationship between flood risk and resilient responses by local communities that develop through social and economic practices. In this way, it was possible to understand the development process of local knowledge that allows operators to manifest their attachment to the place and the social reproduction of the market itself, which is threatened by the crisis of proximity trade and its replacement by tourist activities.

RESILIENCE AND THE PRACTICES OF SPACE

The word resilience is originally derived from the Latin word "*resiliere*", meaning to jump back or bounce back. In the early 1970s, in the context of ecology studies, the term was used to define the time it takes for an ecological system to return to a state of stable equilibrium after the impact of a disturbing event. Resilience was used to measure the ability of systems to absorb changes in state variables, determining how far the system had moved from its equilibrium state.[9]
Resilience constitutes a central reference element in drafting disaster risk reduction programs and sustainable development linked to the 2030 objectives; thus, many analyzes can be found in the literature concerning intervention models that allow for the construction of a resilient community[10]. The need to build and assess the resilience of a city, a community, or a system contributes to generating, especially in the institutional instruments of territorial management, an interpretation of the relationships between global problems and local solutions, which places the responsibilities and solutions on the most vulnerable and least resilient part of the population who suffer the outcome of choices interests positioned on a larger scale.
The interest in social capital has made it possible to analyze how specific groups develop responses to disasters from the perspective of social networks. Social capital based on social cohesion prevents people from leaving disaster-stricken regions by facilitating the mobilization of groups and informally providing a distribution of resources when institutions are unavailable. Disasters result from vulnerability created by political, social and economic environments rather than simply the result of natural hazards. In contexts with high levels of poverty, combined with a lack of access to land and employment, people tend to settle in areas highly exposed to natural hazards. Vulnerable populations have developed a range of creative strategies and complex adaptations that have enabled them to live in risk-prone areas, developing forms of local knowledge that have helped them prepare for and manage crises caused by natural hazards. Local knowledge includes knowledge of hazards, vulnerabilities and capacities. The definition and consideration of local knowledge is an integral part of processes for building resilient systems. Knowing different community capacities is essential for crisis management and local coping strategies. Through the application of their knowledge, communities can help themselves in the absence and before the arrival of external actors. LK is particularly valuable for communities exposed to recurring floods, which have developed culturally rooted practices on living with floods over many generations and coping with political and spatial changes.

THE CATANIA FISH MARKET. THE CONFLUENCE OF CONTRADICTIONS AND TRANSFORMATIONS

The history of the city of Catania is closely intertwined with disastrous events and disasters of various kinds, which have helped determine the future directions of the transformation of the urban fabric. Even in recent periods, the city has been affected by floods and inundations that have caused damage and casualties among the inhabitants. In October 2021, the city of Catania was hit by a disastrous flood that turned the streets of the historic centre into rivers. The extent of the damage was accentuated by concomitant causes attributable to poorly organized land management: lack of a system for conveying water from the Etnean towns, insufficient maintenance of maintenance holes clogged by lava sand from Etna's eruptions, the presence of abandoned urban waste in the streets.
The historic Fish Market is characterized by overlapping cultural meanings, historical processes, and urban and economic issues. The presence of underground watercourses and the proximity to the sea coastline are determining factors for the flood risk exposure of this area. On the one hand, there is no in-depth knowledge of the routes of underground rivers, and on the other, invisibility has reinforced the weakening of the perception of flood risk. The market presents itself as a dynamic context traversed by spatial transformations and catastrophic natural events such as earthquakes and lava eruptions, which have shaped its spatial configuration of streets and squares, with an articulation between houses, shops and stalls of street vendors. The crisis in neighborhood commerce is more acute and severe, resulting in problems in selling products such as fish, meat, fruit, and vegetables and the risk of expulsing historic traders who are making way for restaurant and tourist activities.
The contemporary location market is produced from spatial choices after the transformations conditioned by specific disastrous events. The reconstruction of the city after the earthquake of 1693, imposing the need for a more rational and functional configuration to meet the economic and social recovery requirements, allocated a specific square to the functions of the market in the city center area. Despite the institutional decision to change, merchants and shoppers continued to use the traditional location of the market in the area known as the marina, benefiting both from its proximity to the seaport and from the progressive reclamation of the aquifers present, which led to the construction of palaces, squares and fountains in the late 19th century. Over the centuries, the market strengthened its commercial functions, articulating itself in an area occupying three squares and connecting streets.
As witnessed by the interviews conducted during the field research, the Fish Market presents considerable vulnerabilities concerning flood risk. During the autumn season, with heavy rainfall phenomena, all the spaces of the market flood due to the confluence of rainwater flowing towards the sea from the mountainous areas of the volcano Etna, with the emergence of groundwater from the river called "*Amenano*." While resistance to flood phenomena has facilitated the market's growth, other economic and social factors are responsible for the progressive crisis and spatial contraction of the market. The first aspect relates to the market's close connection with global transformations in the food trade and changes in consumption styles due to housing movements and new forms of social organization of individuals and households. Large-scale food distribution weakens the functions of the historical market. The second aspect concerns the market's spatial and economic transformation directly linked to urban regeneration policies.
The market organization is based on informal economy mechanisms consolidated over time that allow operators and buyers to share information and knowledge in a constant exchange of information and goods. Informality builds a response through context-based experiential processes in which those involved promote dynamic and dialectical modes of action within a specific economic, political and social configuration. Informal activities are not irregular or irrational; they denote phenomena and processes that elude institutional definitions of reality[11]. The geography of market stalls, the types of goods on sale, and the methods of storing and displaying products constitute the essential elements of

local and relational knowledge in the market. Attempts to change regulations based on experience and custom have undermined the market's social, spatial and economic structures, facilitating its contraction.
Market regularization was started in 2008 through a legislative act by the Sicilian Regional Assembly, with Law 38 containing the Norms for the recovery and recognition of the historical value of markets in public areas. With this law, recognizing the historical value of the commercial activities in Catania becomes functional for programming specific structural interventions to maintain and recover monumental works. However, it poses the need to regulate the present sales practices legally. These interventions were accompanied by control and repression actions that hit the traders present at the market who did not possess the requisites to continue working in the market stalls by introducing new regulations and structures for trading practices.
The flood event of 2021 made the social and economic conditions of street vendors even more critical, causing the abandonment and closure of many economic and historical activities.

LOCAL KNOWLEDGE OF RISKS AND ATTACHMENT TO PLACE

Traders describe the historic market as a dead man walking, which suffers from an economic and spatial crisis despite its recognition as a central place in the city's history. The work in the market is based on the definition of a strong link with the city's spaces whose archaeological presence and historical importance are recognized. As Orazio, a fish street vendor inside Pescheria, says: «I work under the historical gate built by Emperor Charles V. Selling fish here becomes something historical» (Orazio, April 2023). Another essential aspect is defining the historical importance of the market, which concerns the selling methods and the organization of the market space. The sellers' behaviour is expressed in food stall presentations, in words that invite buyers to buy, and in the communication tools used to exchange information during work. The market operators possess the knowledge that possessing this knowledge and carrying out these practices makes it possible to reproduce market relations despite its crisis: «When there will be no more vendors and market operators, what will be the characteristics of the historic fish market? » (Orazio, April 2023).
Open-air markets represent microcosms of sociality,[12] as they are characterized by specific models of spatial organization and structured as a distinctive system of social relations centered on producing and consuming goods and services.[13] The methodological choice for the specific study of markets from an ethnographic point of view is not to focus on the types of social processes that take place but on how social processes take concrete and coherent forms within the market. The knowledge of products, spatial context and people constitute an aggregate of values that allows sellers to continue operating in a market in crisis that is perceived as a "dead man walking". Market sellers started their economic activity through kinship or knowledge relationships that still allowed them to establish the basis for the social reproduction of the market. This knowledge forms the basis of the vendors' conflicts against the processes of institutional normalization and regularization of the market, which obliges vendors to use specific ways of preserving food, displaying it, and indicating the origin and different product names. Although numerically more robust within the market, street vendors represent the most vulnerable to controls and the substitution of proximity trade by catering activities aimed at tourists.
The local knowledge of market traders takes shape from practices acquired over time through the accumulation of experience over generations, including society-nature relations and community institutions. These practices bring into play processes of appropriation and re-appropriation of spaces, designed and planned, then used and transformed according to different interests and logics.[14] Local knowledge in the market concerns the manifestations of flood phenomena. Traders understand the movements of water during a flood when its level increases due to the increased flow of the underground river flowing below the street level. This knowledge relates to the timing of the floods, as after the

underground river rises, the streets and market squares are swept away by a wave of water flowing downstream from the mountain locations. The fish market is located at the lowest point below sea level, in an area that, until the beginning of the 20th century, was mainly occupied by water, coastline and marshland. The fish sellers, who have been working in the area for a long time, have not been taken into account concerning the latest maintenance work on the road surface and the project to restore the fish market tunnel. The river networks and knowledge related to the positioning of the market constitute information learned during work experiences in the fish market and through transmission between old and new market operators.

CONCLUSIONS

The in-depth analysis of the market case study in the context of the city of Catania highlights the limits of an approach to resilience as a capacity to be measured or built, questioning the idea that the state prior to a calamitous event is necessarily considered optimal or desirable and that therefore collective action should be limited to rebuilding the conditions for a return to that state of normality.

This research shows the importance of adopting a different positioning in the study of urban transformations, demonstrating that resilience cannot be considered a passive process but constitutes an active assemblage in which new relational networks are defined between objects, spaces, people and social groups. Those chains of connectivity that actor-network theory analyzes in the dialogical relationship between elements that have value[15]. In this sense, research shows that local knowledge and forms of place attachment can help communities prepare for and manage crises caused by natural hazards, allowing them to link what communities know about natural hazard risks and how they perceive these risks with the experimentation of specific models and activities of participation, design and transformation. Place attachment catalyzes individuals to come together based on the shared experience of where they live, which supports perceived levels of community cohesion and effectiveness. A more spatialized understanding of disasters could overcome these dual limitations - the constraints of defining disasters as isolated episodes and planning for recovery as emergency responses, paying attention to the socio-spatial production of risk.

Addressing the question of resistance and the survival of alternative forms of life means observing and interacting with those practices that offer subjects the strength to resist and to be able to act in everyday life in contexts in which these assumptions are constantly challenged[16]. For this reason, the research aimed to understand how, within specific conditions concerning the tension between flood risk and spatial transformations, forms of social life are in friction with the technical design visions that continue to decide on restructuring city spaces. In a context vulnerable to flood risks and economic and spatial crises, such as the Pescheria market, street vendors use their knowledge and attachment to the place to continue manipulating and transforming spaces. The market traders' ability to give continuity to the hawker economies and maintain social relations allows a constant interchange of services, resources and opportunities for reproduction within the context. Specific historical and territorial knowledge plays a role in the configuration of spatial and social relations as a means of defence against the erosion of the right to presence caused by market normalization and restructuring processes.

NOTES

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SECTION FIVE

ESTABLISHING THE URBAN SUSTAINABILITY INDEX: ASSESSING URBAN SUSTAINABILITY FOR EFFECTIVE CHANGE

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INTRODUCTION

This paper addresses contemporary challenges such as climate change and socioeconomic inequality within the context of urban sustainability. As urban areas increasingly serve as epicentres of human habitation, there is a compelling need to explore their potential as focal points for innovation, collaboration and transformative change. In this study, we introduce the Urban Sustainability Index (USI), which incorporates eight independent parameters derived from established indicators to assess a selection of representative cities. The USI provides a robust foundation for future research, enhancement and the development of a more comprehensive, holistic and actionable approach to sustainability. Our analysis of the findings underscores the diverse array of challenges confronting cities worldwide, with specific emphasis on issues related to emissions, air pollution, green spaces and inequality. To effectively address these challenges, a concerted and multi-pronged effort is imperative, as underscored by the Urban Sustainability Index (USI). This research strongly advocates for the formulation of targeted action plans, fostering collaboration between the public and private sectors, promoting active citizen participation and empowering women. By addressing existing deficiencies and embracing novel, effective solutions, we can pave the path towards the establishment of liveable and sustainable urban environments. This study encourages stakeholders to perceive cities as catalysts for positive change, thereby facilitating a future where urban areas assume a pivotal role in addressing global sustainability challenges.

Sustainability

Sustainability has been a critical focus in various fields, with its roots tracing back to forestry practices in 1713, when Hans Carl von Carlowitz recommended that no more wood should be harvested than could be regrown.[1] Modern sustainability encompasses economic, social and environmental dimensions, as highlighted by the Brundtland definition: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”[2] This paper presents the Urban Sustainability Index (USI) as a novel approach to assessing urban sustainability by evaluating eight key parameters across twelve cities worldwide.

METHODOLOGY

The USI's methodology involves aggregating data from diverse sources, calculating parameter scores and illustrating results through radar charts and bar graphs. The index is applied to twelve cities representing various geographical locations and development levels to ensure a comprehensive assessment.

Parameters of the Urban Sustainability Index (USI)

The Urban Sustainability Index (USI) assesses sustainability using eight dimensions divided equally between technological/environmental and socio-economic aspects. This dual focus ensures that the USI addresses the multifaceted nature of urban challenges and opportunities. Each of the eight dimensions is measured on a scale of 0 to 100, with data sourced from publicly available repositories such as the United Nations (UN) and the World Health Organization (WHO).

USI Parameter I: Air Pollution (Technical/Environmental Parameter)

Air pollution, particularly fine particulate matter (PM2.5), is a significant health hazard, linked to respiratory, cardiovascular and cerebrovascular diseases.[3] It also contributes to climate change and environmental degradation. The World Health Organization (WHO) estimates seven million premature deaths annually due to air pollution.[4] The USI uses data from the World Air Quality Project to calculate an air pollution score based on the number of days a city falls within various air quality categories.
Data Sources: World Air Quality Project (World Air Quality Index).[5]
Impact: Reducing air pollution is vital for public health and environmental sustainability, improving the overall livability of cities.

USI Parameter II: Water Supply (Technical/Environmental Parameter)

Access to clean water for drinking, sanitation and hygiene is crucial for preventing disease and reducing health risks from chemical contaminants.[6] For the USI the water supply score is calculated as the geometric mean of the percentages of the population with access to safe drinking water, sanitation and hygiene facilities.
Data Sources: 2021 WHO and United Nations Children's Fund (UNICEF) report on access to safe drinking water, sanitation and hygiene.[7]
Impact: Ensuring a clean and reliable water supply supports public health, economic development, urban functionality and resilience against climate impacts.

USI Parameter III: Housing (Socioeconomic Parameter)

Adequate housing is essential for health, safety and overall quality of life. Poor housing conditions, particularly in slums, pose severe health risks including high child mortality,[8] the spread of infectious diseases[9], malnutrition[10] and violence[11]. Data from the United Nations Human Settlements Programme (UN-Habitat) helps derive the USI housing score, representing the percentage of the urban population living outside slums.
Data Sources: UN-Habitat data on the percentage of urban populations living in slums.[12]
Impact: Improving housing conditions is critical for enhancing urban living standards and reducing health risks.

USI Parameter IV: Corruption and Crime (Socioeconomic Parameter)

Corruption and crime undermine development by increasing costs[13] and reducing investment effectiveness.[14] High levels of corruption can deter foreign investment and impede the delivery of public services, while crime affects the quality of life and economic productivity. The related USI score combines rescaled murder rates and Corruption Perception Index (CPI) values.

Data Sources: Corruption Perception Index (CPI)[15] by Transparency International and murder rates from the United Nations Office on Drugs and Crime (UNODC).[16]
Impact: Addressing corruption and crime is crucial for creating a stable and conducive environment for economic activities and social well-being.

USI Parameter V: Emissions (Technical/Environmental Parameter)

Cities contribute significantly to global greenhouse gas emissions and energy demand.[17] The emissions score in the USI was calculated using a combination of greenhouse gas emissions data and waste management data. For three cities additional data were obtained from further sources (for details see [18]).
Data Sources: C40 Knowledge Hub[19] and the World Bank's "What a Waste" Report.[20]
Impact: Lowering emissions through efficient public transport, energy-efficient buildings and waste management is essential for combating climate change and promoting sustainable urban development.

USI Parameter VI: Green Space (Technical/Environmental Parameter)

Urban green spaces mitigate air pollution[21] reduce heat islands[22] and promote mental well-being[23]. They enhance the aesthetic quality of urban areas and offer recreational opportunities, improving the quality of life. Distribution and visibility of green space are especially important factors in achieving these goals. The green space parameter for the USI was calculated using the relative proportion of a city's total area covered with green space and the distribution of this greenery throughout the city.
Data Sources: Green View Index[24] and Husqvarna Urban Green Space Index (HUGSI).[25]
Impact: Expanding and maintaining green spaces are critical for enhancing urban resilience, public health and environmental quality.

USI Parameter VII: Inequality (Socioeconomic Parameter)

Inequality in income, education and access to services can hinder overall development and exacerbate social tensions. High inequality levels often lead to reduced economic mobility and opportunities for large segments of the population, affecting social cohesion and stability. Inequality affects access to essential services and overall societal well-being. The USI parameter for inequality was calculated by combining gender and income inequality within cities.
Data Sources: Gini-Coefficient[26] and the Subnational Gender Development Index (GDI).[27]
Impact: Ensuring equality helps all inhabitants enjoy essential services, improving overall societal health and economic stability.

USI Parameter VIII: Human Development (Socioeconomic Parameter)

Human development, encompassing education, health and income, is fundamental to assessing the well-being of a city's residents. High human development levels indicate a city's capacity to provide a good quality of life and support sustainable growth. The Human Development Index (HDI)[28] is preferred over the gross domestic product (GDP) for measuring well-being, incorporating education, life expectancy and income. The related USI parameter is calculated from the Subnational Human Development Index for more precise city-level data.
Data Sources: Subnational Human Development Index[29] by the Global Data Lab.
Impact: Focusing on human development ensures that cities prioritize the well-being of their residents, leading to more sustainable and inclusive growth.
The selection of these eight parameters for the USI ensures a balanced and comprehensive assessment of urban sustainability. By addressing both socioeconomic and technical/environmental aspects,[30] the USI provides a nuanced understanding of the challenges and opportunities cities face in their pursuit of

sustainable development. This dual approach allows for targeted interventions and policies that can effectively improve urban sustainability across diverse contexts.

Selection of Cities for the Urban Sustainability Index (USI)

The USI is calculated for twelve cities, chosen to represent a diverse array of geographical locations, economic conditions and stages of urban development. This selection aims to provide a comprehensive understanding of urban sustainability across different contexts, highlighting unique challenges and opportunities within each city. The cities included in the study are:

1. Addis Ababa, Ethiopia (Africa)
2. Amsterdam, The Netherlands (Europe)
3. Bangkok, Thailand (Asia)
4. Copenhagen, Denmark (Europe)
5. Dubai, United Arab Emirates (Asia)
6. Ho Chi Minh City, Vietnam (Asia)
7. Johannesburg, South Africa (Africa)
8. Lagos, Nigeria (Africa)
9. Mexico City, Mexico (North America)
10. Sao Paulo, Brazil (South America)
11. Toronto, Canada (North America)
12. Vienna, Austria (Europe)

Reasons for Selection

Geographical Diversity: The cities were chosen to cover various geographical regions, ensuring that the USI captures a wide range of environmental conditions, urban landscapes and climate zones. This diversity helps in understanding how geographical factors influence urban sustainability.

Economic Varieties: The selected cities represent a spectrum of economic conditions from developing to developed economies. This includes rapidly growing urban centers like Lagos and Addis Ababa, emerging economies such as Ho Chi Minh City and Bangkok and highly developed cities like Amsterdam, Copenhagen and Toronto. This variety allows for the assessment of how economic status impacts sustainability efforts and outcomes.

Human Development Levels: Cities with differing levels of human development, as indicated by metrics such as the Human Development Index (HDI), were included. This ensures that the USI can effectively compare and contrast urban sustainability in contexts where human development indicators vary significantly.

Urbanization Stages: The cities are at various stages of urbanization, from rapidly urbanizing centers with significant rural-urban migration to well-established metropolitan areas. This mix helps in understanding how the stage of urban development affects sustainability challenges and solutions.

Cultural and Policy Differences: Including cities from different cultural backgrounds and governance models provides insights into how cultural values and policy frameworks influence urban sustainability. For instance, Copenhagen and Vienna, known for their strong environmental policies and social welfare systems, contrast with cities like Dubai, where rapid modernization is coupled with unique environmental challenges.

City Profiles

The selected cities provide a diverse and representative sample for the Urban Sustainability Index, capturing a wide array of challenges and practices in urban sustainability. By analyzing these cities, the USI aims to generate insights that are broadly applicable and can inform policy and planning in varied urban contexts worldwide.

Addis Ababa (Ethiopia, Africa): As the capital of Ethiopia, Addis Ababa is experiencing rapid urban growth. Challenges include managing infrastructure development, pollution and providing adequate housing and services to its expanding population.
Amsterdam (The Netherlands, Europe): Known for its progressive urban planning, Amsterdam excels in sustainable transport, green spaces and water management. It provides a benchmark for sustainability practices in highly developed urban areas.
Bangkok (Thailand, Asia): Bangkok faces typical challenges of megacities in developing countries, such as air pollution, traffic congestion and flood management. It provides a case study of urban sustainability in a rapidly growing economy.
Copenhagen (Denmark, Europe): Renowned for its ambitious climate goals and sustainable urban design, Copenhagen serves as a model for integrating environmental, economic and social sustainability in a developed context.
Dubai (United Arab Emirates, Asia): Dubai's rapid urbanization and development pose unique sustainability challenges, particularly in terms of resource management and environmental impact in an arid climate.
Ho Chi Minh City (Vietnam, Asia): As a major economic hub in Vietnam, Ho Chi Minh City deals with rapid population growth, industrialization and associated environmental and social issues.
Johannesburg (South Africa, Africa): Johannesburg is the largest city in South Africa and a major economic hub for the continent. The city faces significant challenges including socioeconomic inequality, infrastructure deficits and environmental degradation. However, Johannesburg is also making strides in sustainable urban development through projects aimed at improving public transport, housing and green spaces.
Lagos (Nigeria, Africa): Lagos is one of the fastest-growing cities in the world, experiencing rapid population growth and urban expansion. Key challenges include severe traffic congestion, inadequate infrastructure and poor waste management. Efforts to enhance sustainability focus on improving public transportation, reducing flooding and expanding access to clean water and sanitation.
Mexico City (Mexico, North America): As one of the largest and most densely populated cities in the world, Mexico City deals with air pollution, water scarcity and traffic congestion. Sustainable initiatives in the city aim to tackle these issues through improved public transportation systems, green infrastructure and policies to reduce emissions and manage water resources more effectively.
Sao Paulo (Brazil, South America): Sao Paulo is Brazil's largest city and an economic powerhouse. It faces numerous urban challenges such as traffic congestion, pollution and social inequality. The city is working on sustainability through initiatives that promote renewable energy, enhance public transportation and foster social inclusion and environmental protection in urban planning.
Toronto (Canada, North America): Toronto is known for its cultural diversity and economic vitality. The city's sustainability efforts focus on reducing greenhouse gas emissions, enhancing public transportation and creating green spaces. Toronto's comprehensive approach to urban sustainability includes initiatives in waste management, energy efficiency and social equity.
Vienna (Austria, Europe): Vienna consistently ranks high in global livability indexes due to its effective urban planning and high quality of life. The city excels in public transportation, green spaces and energy-efficient buildings. Vienna's sustainability practices include extensive recycling programs, innovative water management systems and policies promoting social cohesion and economic stability.

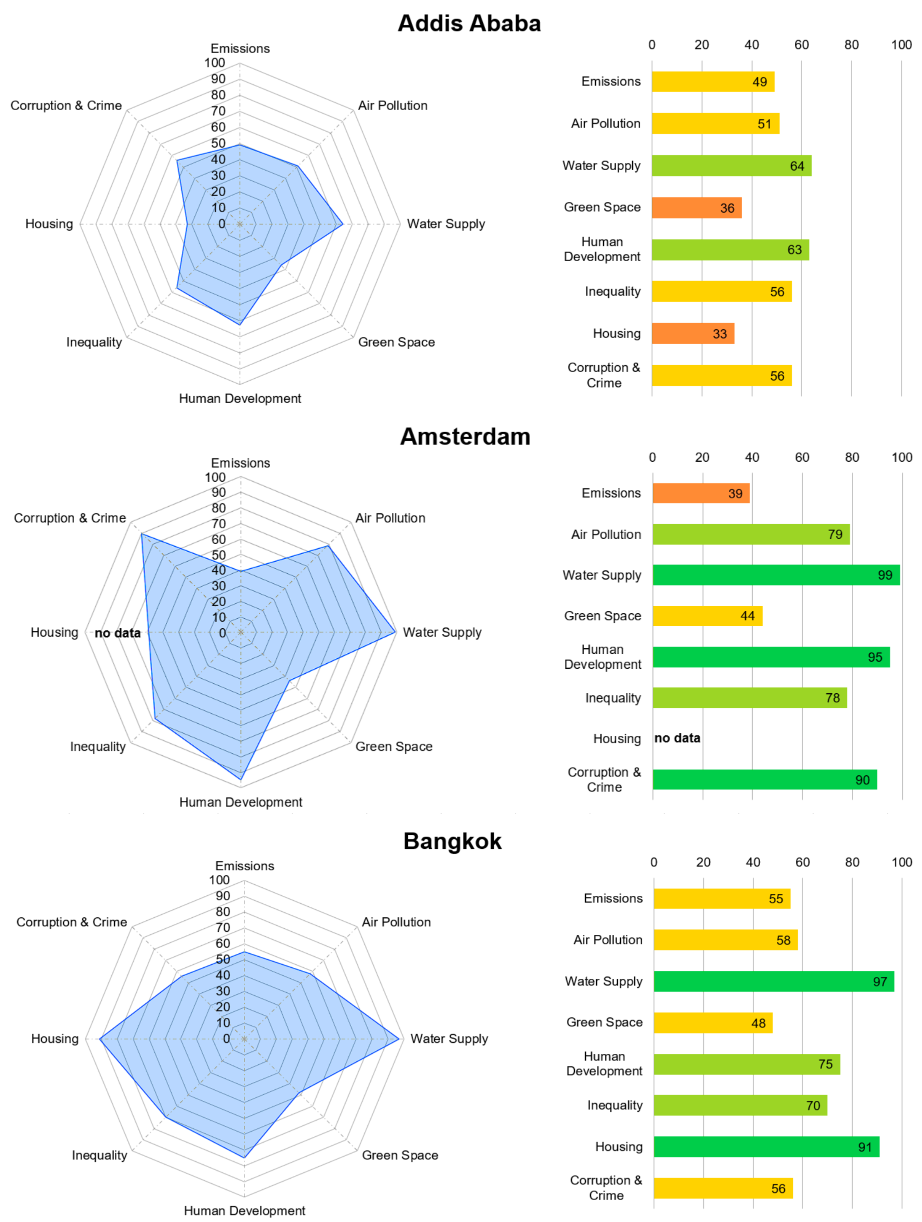

Figure 1. USI values for Addis Ababa (Ethiopia, Africa), Amsterdam (The Netherlands, Europe) and for Bangkok (Thailand, Asia).

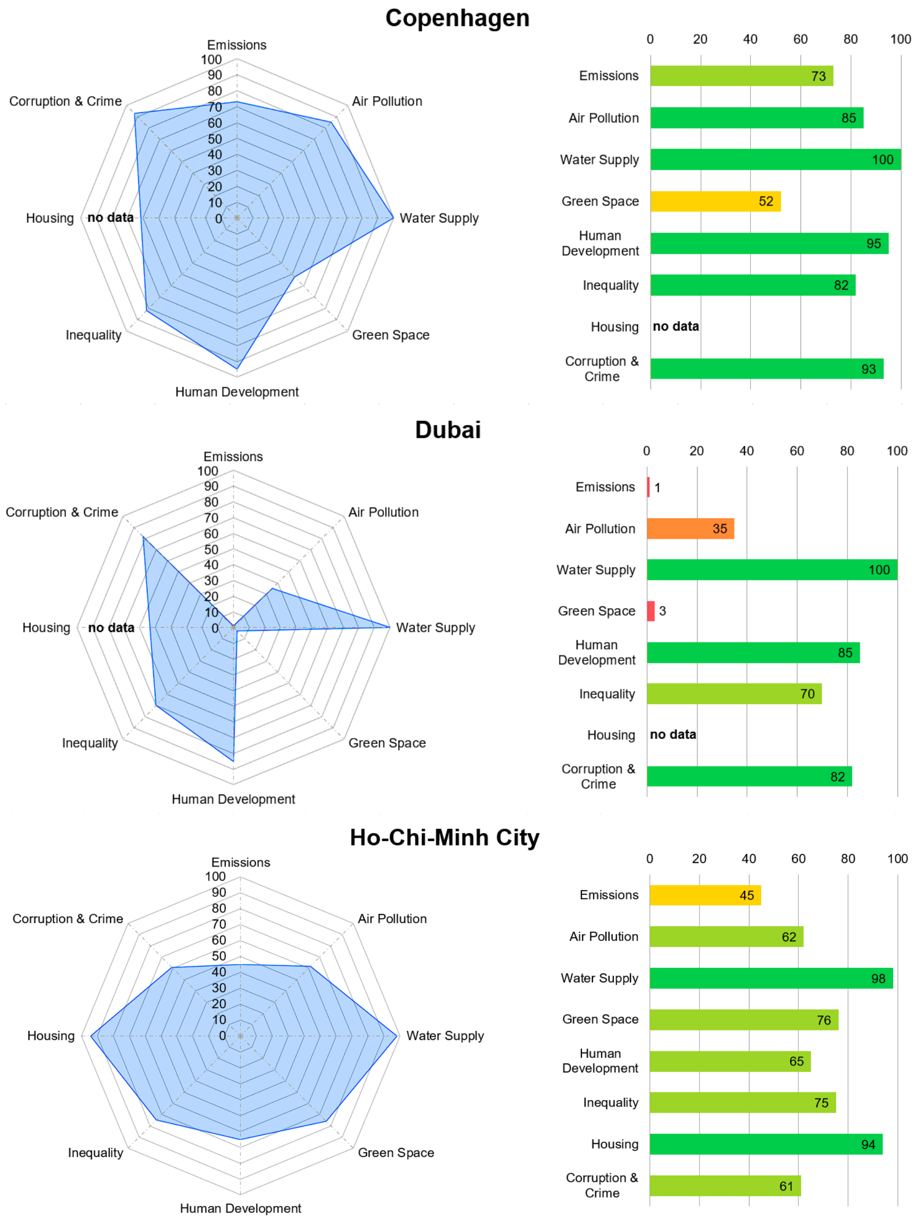

Figure 2. USI values for Copenhagen (Denmark, Europe), Dubai (United Arab Emirates, Asia) and Ho-Chi-Minh City (Vietnam, Asia).

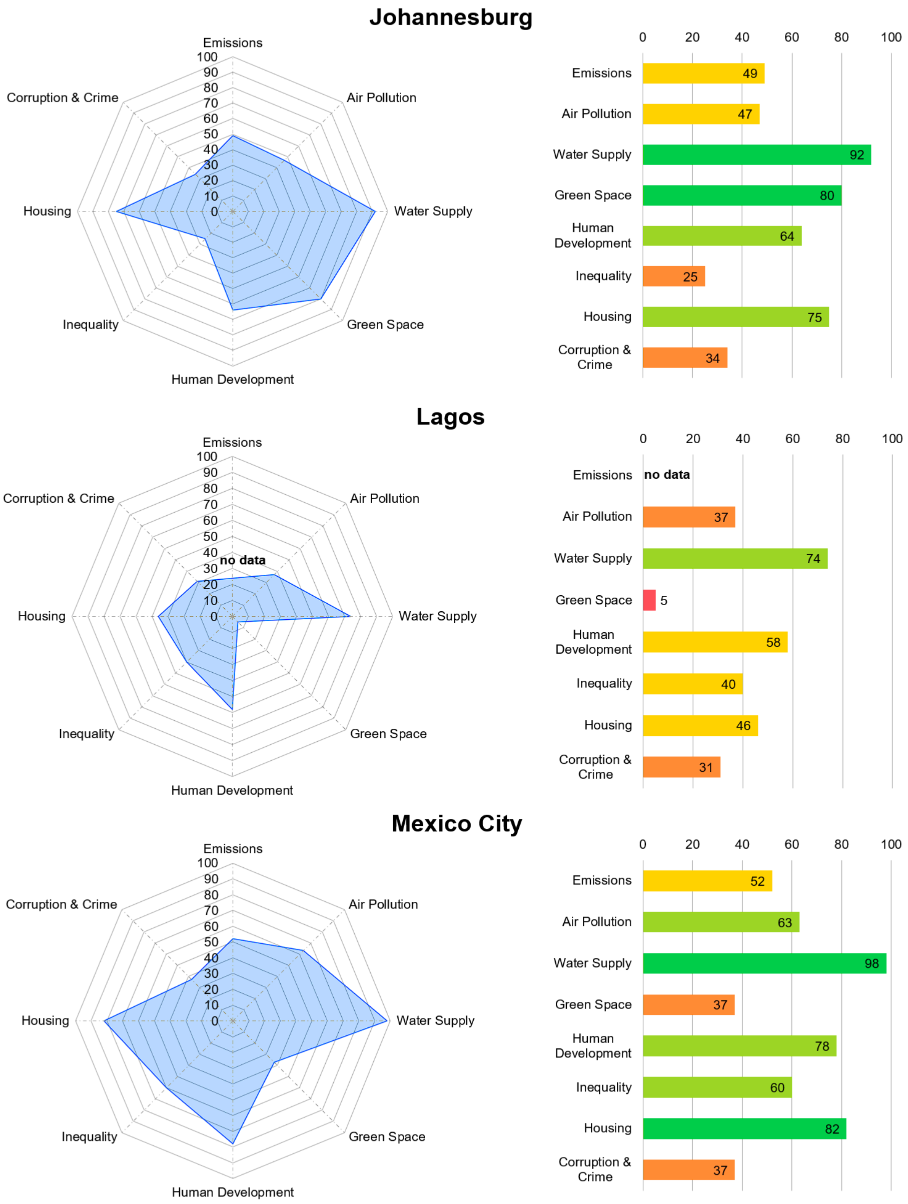

Figure 3. USI values for Johannesburg (South Africa, Africa), Lagos (Nigeria, Africa) and Mexico City (Mexico, North America).

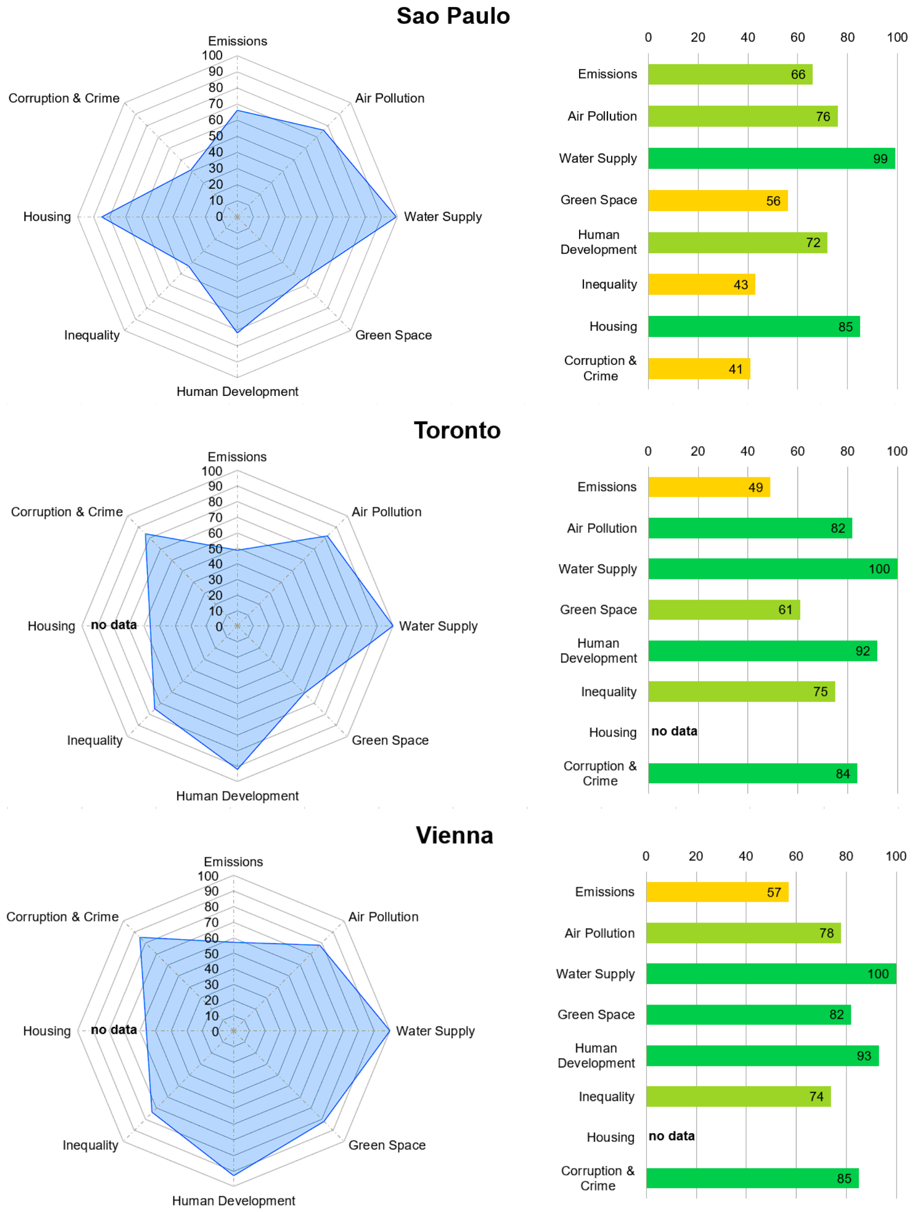

Figure 4. USI values for Sao Paulo (Brazil, South America), Toronto (Canada, North America) and Vienna (Austria, Europe).

RESULTS AND DISCUSSION

The application of the USI reveals significant insights into urban sustainability. For instance, high correlations are found between water supply and housing, indicating that these parameters often reflect similar underlying issues. Conversely, no significant correlation was observed between emissions and green space, suggesting the need for distinct strategies to address these areas.

Figures 1 to 4 present the USI for the twelve selected cities. In the graphical bar graph illustration, five intervals were chosen to differently colour higher and lower values. Values are coloured red 0 to 20, orange from 20 to 40, yellow from 40 to 60, light green from 60 to 80 and dark green from 80 to 100.

It is important to note that our calculations for the urban sustainability index indicate that Bangkok performs better than Amsterdam in terms of emissions. This may initially seem counterintuitive to some readers. However, both cities exhibit similar per capita values for CO_2 emissions and waste generation. According to the World Bank report, from which the waste data was sourced, Bangkok has a notably high composting rate of 48.7%. This is attributed to the substantial proportion of organic waste in the city's waste stream, significantly improving Bangkok's emissions score. While the accuracy of these data might be debatable, this World Bank report remains the most reliable source available for our analysis.

RECOMMENDATIONS FOR ENHANCEMENTS OF THE USI

The USI provides a comprehensive framework for assessing urban sustainability across diverse cities. However, continuous improvement and adaptation are essential to enhance its effectiveness and relevance. Based on the findings and limitations identified during the application of the USI, the recommendations are proposed regarding enhanced data collection and quality, broader application and comparative studies, refinement of parameters and methodologies, increased stakeholder engagement, policy integration and support as well as technological and methodological innovations. These recommendations aim to provide a forward-looking perspective, addressing the key areas for enhancing the USI's effectiveness and ensuring its continued relevance in assessing urban sustainability.

The USI was first presented to the public in London at the AMPS Livable Cities Conference 2024. During this presentation, several insightful questions and comments were raised by the attendees. These points highlight areas for further consideration and refinement of the USI. Discussion after the presentation touched the points of examining smaller structures such as neighborhoods or districts within cities, resilience vs. sustainability, the consideration of trade-offs between different aspects of sustainability in the USI and the perception of one participant that the USI is colonialist.

The feedback received at the conference provides valuable insights for the continued development and refinement of the Urban Sustainability Index. By incorporating these suggestions, the USI can become a more comprehensive, sensitive and practical tool for assessing and promoting urban sustainability. Addressing the concerns and suggestions raised will enhance the index's relevance, accuracy and acceptance across diverse urban contexts.

CONCLUSION

The USI presents a valuable tool for assessing urban sustainability, offering detailed insights that can inform policy and improve urban planning. Future enhancements in data collection and methodological refinements will further strengthen the index's utility. Continued research and application across diverse cities will enhance our understanding of urban sustainability and drive effective change.

The Urban Sustainability Index is a dynamic tool that requires continuous improvement to remain effective in assessing and promoting urban sustainability. By enhancing data collection, broadening its application, refining parameters, engaging stakeholders, aligning with policies and leveraging technological innovations, the USI can provide even more valuable insights and drive meaningful change in cities worldwide. These recommendations aim to guide future developments and ensure that the USI remains a robust and relevant tool in the pursuit of sustainable urban development.

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MULTI-DISCIPLINARITY IN GREEN AND BIODIVERSE URBAN SPACES

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INTRODUCTION

It is a common notion that what make cities "livable" is the presence of open green urban spaces. Historically, urban planners and landscape architects have endeavored to incorporate green amenities into both existing and new neighborhoods by developing park policies, plans, and concrete urban parks. Today's poly-crisis of climate change and biodiversity loss seems to both enforce this notion and the urban green spaces as the primary remedies to mitigate and handle these crises. Behind this both philosophical and functional focus on the green urban spaces is the acknowledge of how humans have detached themselves from nature and how this relationship might be re-established.

In recent years the terminology has shifted from park policies to urban nature suggesting that something is changing when we talk about nature and natural phenomenon in urban settings.

The concept of urban nature seem itself to be closely linked to the above-mentioned poly-crisis as the term indicates the human-nonhuman relation in an urban setting pointing towards the fact that today most of us live in urban environments detached from natural and rural areas.

Apart from the shift in terminology we also see shifts in how and by whom urban nature is argued and designed; urban public parks have for nearly 200 years been part of what we may term a landscape architectural program, and a spatial typology argued for its recreational purposes and aesthetic function and dimensions within the urban fabric. Urban nature projects seem to be argued by other considerations such as biodiversity, ecology, sustainability and resilience, and the design teams now a mixture of professionals bringing together different knowledge fields and notions of nature. Likewise, non-professionals have become increasingly active partners in the design and maintenance processes of urban nature. On the one hand these changes impact the design process, the role of the landscape architect, and the aesthetic ideals. On the other hand, they can also be seen as to re-invigorate or re-vitalize older typologies, roles and theories and ideas from landscape architectural legacy.

In his seminal book on urban nature Matthew Gandy[1] states that his book is not about 'designed nature'. This paper is about designed nature; it takes it's point of departure in landscape architecture and landscape architectural thinking and doing.

First a short introduction to urban green spaces and to Danish Park policies is given adding background to the following description and discussion of the two examples on how the term urban nature is interpreted and given form as public accessible urban parks. The examination is based on literature studies and semi structured qualitative interviews with keypersons behind the two examples on urban nature projects examined in this paper.

BACKGROUND ON GREEN URBAN SPACES

In Raymond Unwin's book, *Town Planning in Practice* from 1909 it is argued that urban green spaces are important parts of modern urban planning practice, and they are to be regarded main components in what makes a city livable,

'We shall need to secure still more open ground, air space and, sunlight for each dwelling; we shall need to make proper provision for parks and playgrounds, to control our streets, to plan their direction, their width, and their character, so that they may in the best possible way, minister to the convenience of the community'.[2]

Unwin expressed a common notion among the early modernistic urban planners, namely that the dense, dirty and crowed industrial city was to be infused with light and air to make the cities livable. A similar emphasis on the contact to nature and landscape to make cities livable is to be found in Ebenezer Howard, Gardens Cities of Tomorrow.[3] Also, Le Corbusier aimed at cities as, 'Towers in a park setting'[4] suggesting that not only needed the cities green urban spaces, but the city to be located in the park.

Danish Park Policies

Four key documents in Danish urban and urban green space planning documents and illustrates how these ideas informed the Danish urban discourse and especially the development of Greater Copenhagen. The four documents are, *Park Politik for Sogn og Købstad*, from 1931 by landscape architect Carl Theodor Sørensen[5], in which he presented a range of ideas on public green urban spaces, leisure areas, playgrounds, allotment gardens, urban green typologies and nature conservation.

In the second key document, *Københavnsegnens grønne Omraader. Forslag til et System af Omraader for Friluftsliv*, from 1936, the question on how to develop Copenhagen in ways that provided access to green areas for the citizens while also providing space for housing, industry and infrastructure. C. Th. Sørensen co-authored this document with Olaf Forchhammer.[6] The *Fingerplan*, from 1947 by Dansk Byplanlaboratorium[7] is the third key document outlining the spatial and functional relationship and structure between the build area and the open landscape.

The fourth key document, *Parkpolitik -boligområderne, byerne og det åbne land*, from 1988 is co-authored by the three landscape architects, Sven-Ingvar Andersson, Ib Asger Olsen and Annelise Bramsnæs[8] in which they added planning of the rural areas and the transformation of existing built-up and industrial areas to the range of landscape architectural assignments.

A common notion of nature and landscape characterize the four documents: Nature and landscape within cities are a pre-condition for livable cities and conditioned by urban life.

This notion was turned into a landscape architectural program for the twentieth century, defining the tasks as,

- Housing
- Recreation – parks, sports facilities, gardens, playgrounds
- Infrastructure
- Infrastructure, energy planning, landfills
- Cemeteries/graveyards
- Public, institutional, facilities

Today defined as, The Green Cultural Heritage[9] and considered important contributions to the formation of the Danish Welfare State.

EXAMPLES OF URBAN NATURE PROJECTS

In this section two examples of urban green space designs are examined to better understand how and by whom urban nature projects come into being.

Example 1: Herlev Hospital

The first example is the refurbished out-door spaces covering an area of 95.000 m2 around a large Danish public hospital, Herlev Hospital, located in Greater Copenhagen by Stig Lennart Andersson (SLA)and from 2010-2020 (fig. 1)

SLA is deeply concerned with questions on biodiversity, ecology and resource management able to address impacts of the current poly-crisis.

"City nature is something we humans design to solve our self-induced urban problems. It is informed by the processes and phenomena of nature. It creates habitats for plants and animal species, thus strengthening and increasing our cities' biodiversity. (…) City nature results from a conscious design action, and its success is measured by whether it makes our cities more livable. In terms of ensuring that all species present within them (humans, birds, insects, etc.) can *survive*. But likewise in terms of ensuring that we all have something to live *for.'*[10]

City nature is to SLA a remedy to solve some of the negative impact urbanization has had on biodiversity and on humans, and cities are to be regarded as more-than-human habitats. City nature is regarded a product of a conscious design process producing a nature to replace the nature we have detached us from and lost contact with.

Figure 1. Plan of Herlev Hospital. Source: SLA

An interview with one of the design leading landscape architects was conducted to better understand how SLA works with this urban (City) nature approach.

The interview began with a question on the changes that have been made in the staff composition.

Running through the employee contact information[11] there where: 49 Landscape architects; 13 Urban planners and urban designers;1 Landscape engineer; 31 Architects; 1 Anthropologists; 2 Cultural geographers; 4 Biologists; 2 light and dark designers; 1 Philosopher; 1 employee educated within educational psychology and 18 others.

In practice the employees are divided into teams consisting of landscape architects, architects and urban planners, to which the different in-house experts coming from other disciplines are affiliated when needed according to the project phases, special site conditions etc.

During the interview it was argued that biodiversity is not only a question of the number of species, but biodiversity had also become an aesthetic guideline and value adding meaning to the design as a morally and ethical sustainable and responsible design principle in opposition – spatially, aesthetically and programmatically - to architectural construction and in this case to the in-door world and clean aesthetics of the hospital design (fig. 2)

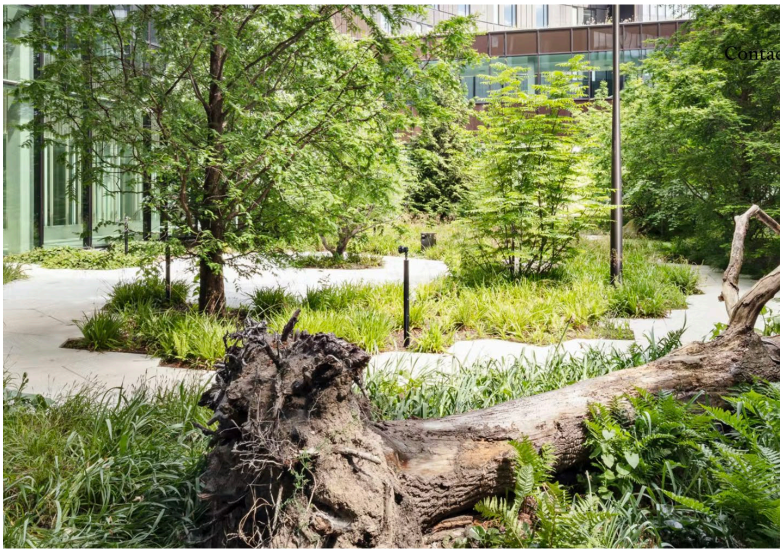

Figure 2. Herlev Hospital. One of the out-door spaces. Source: SLA

The design process itself was described as collaborative and as guided by experiments with different soil conditions, i.e., mineral earth, debris, gravel and plantings that are supposed to just grow creating a lush, overwhelming and diverse impression of natural phenomena. It was also emphasized that the design process no longer is regarded as ending with a design project but as a *designing process*, which is followed and sought supported to a more far-reaching degree than before to support the design development and the client's understanding of the designing idea.

Example 2: Tarup-Davide

Figure 3. Tarup-Davinde. Landscape view from one of the entrances. Source: author

Tarup-Davide is an extraction area covering approx. 1400 ha. of which 400 ha have been converted into a regional park landscape. The area is located on Fyn and 10 kilometers south-east of Odense the third largest city in Denmark. Extraction activities are still in operation on the area, but when the extraction activities stop the municipalities of Odense and Faaborg-Midtfyn purchase the areas with the purpose to transform them into a regional park landscape (fig. 4).

To run the area daily the non-profit company Tarup-Davinde I/S (TD) has been formed. The five employees refer to the two municipalities. Two of these have a background in natural science, a handy man, an office employee and a trainee. TD's main tasks is to disseminate knowledge on nature, support better health, stimulate social activities and play and to increase the level of biodiversity. TD collaborates with the citizens groups as active partners in fulfilling these tasks.

To organize the partnership-model TD has developed a five-phase strategy.

Phase 1: Ideas and conflicts are regarded a kick starter and opportunity to establish relationships and start a dialogue. In phase 2 new users are asked to organize themselves as a legal entity to form partnerships between equals. A partnership agreement is formed in phase 3 describing with what the parties contribute, how to finance the activity, as well as a section on insurance for the volunteers.

In following up on the partnership TD organizes annual meetings (phase 4), to evaluate, correct and plan for the upcoming season. In phase 5 TD invites the area's users every two years to an event where the groups show and share their experiences with the public and other groups.

The partnership model offers another form of poly-disciplinary collaboration than in example 1. as it is between professionals (authorities) and non-professionals citizens groups. The collaboration is organized by a structure plan designed by an external landscape architect consultant, forming the overall guiding framework around the different activities and physical design interventions.

TD is in control of roads, paths, the terrain formation, some of the plantings in the area. Likewise, is the area's level of biodiversity decided and coordinated, and controlled solemnly by TD. TD's role is to follow the structure plan and suggest where to locate the various new activities, for example mountain bike tracks, which the citizens groups 'design' and construct themselves.

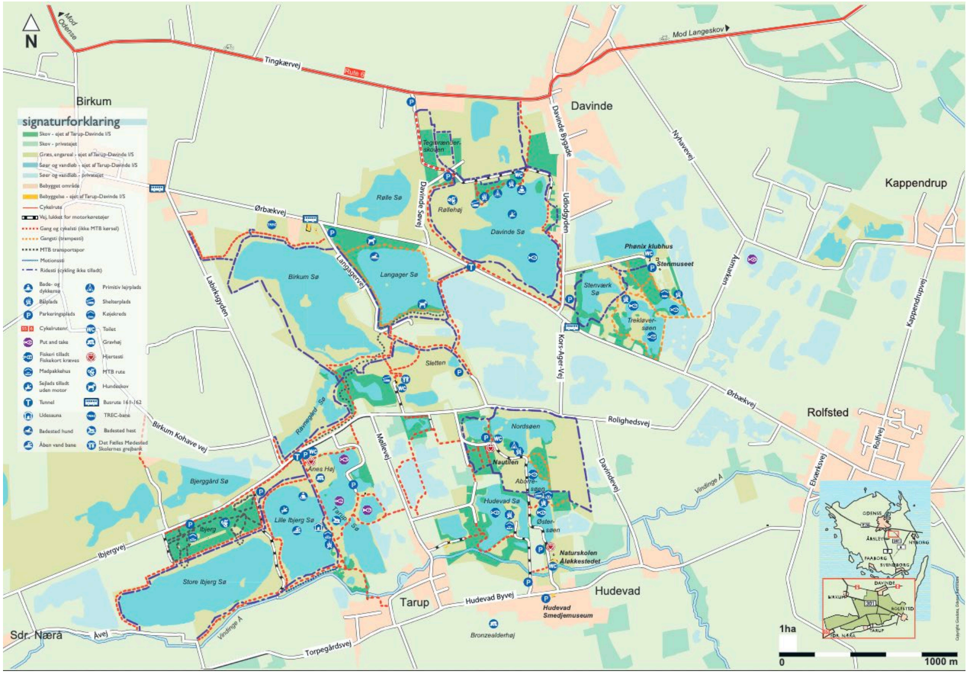

Figure 4. Tarup- Davinde plan Source: Tarup-Davinde I/S

Quantitative diversity regarding both biodiversity, social activities and programs are the both the ambition, measurement and goal in TD's doings, meaning that any architectural conceptual considerations on spatial, proportional and sensory experience and relations between the individual elements are only guided by the structure plan. The motto seems to be the more the better – i.e., to a certain degree as not every new species encountered in the area is regarded a token of success - the natural succession process is carefully observed and stopped at a certain level by TD.

DISCUSSION

The two examples presented above illustrates two different forms of urban nature spaces in Denmark and how they come into being. Even though example 2, Tarup-Davinde, is located outside a city it is conditioned by urban society[12] and functions as an urban park by providing leisure space and activities to urban citizens, why both examples may be described as examples of urban nature projects.

Despite the shift in terminology from park and park policies to urban nature and biodiversity, both examples can be argued in line with Danish Park policy tradition, i.e., to provide public green spaces for recreation and nature experiences aimed at urban citizens, as described both by Sørensen,

'park policy, is something much more serious than a bit of city beautification, it ranks with the other social measures necessary for the existence of the citizens' [13] and later by Andersson et al. in 1988.

In both documents it is stated that the purpose of parks and urban greenery is to make the city livable and 'to make the experience of nature physically and mentally accessible to urban citizens',[14] thus underlining both a recreational and an educational purpose which we also encounter above in the two described examples, Herlev Hospital and Tarup-Davinde.

Andersson et al. adds to these purposes three others: providing space for and stimulate social interaction; contribute to the perception of the structure of the city and/or the urban district, and to satisfy a need for beauty.[15] Beauty is here equaled with nature and landscape and the experience of nature and landscape defined as a human need which is a tricky statement as it is impossible both to define what beauty is but also that it is likely as much as a need as a cultural expectation[16] and norm. The latter also emphasized by Fisher,[17] Duvall et al.[18] and Braae, 2023.[19]

The different positions within the discourse outlines the complexity of the question on urban nature and the term itself, but also that beyond the discussion on need and/or cultural expectations it is still a political question which relevance is increasing proportionally with the development in today's interconnected poly-crisis. The purpose of using the green urban spaces to structure the urban fabric is not specifically addressed in the two examples and the term beauty replaced by experience of nature and natural phenomena.

In the two examples we see different forms of poly-disciplinary collaborations.

In example 1, Herlev Hospital, the poly-disciplinarity is organized within a group of different professional teams at SLA. Whereas in example 2 Tarup-Davinde the poly-disciplinarity occurs between groups of professionals and non-professionals. The latter framed as a partnership model whereas the first is a more traditional landscape architectural praxis set-up.

At SLA the design process is described as 'flat' and involving many disciplines but mainly lead by landscape architects and architects.[20] A shift from formal aesthetics to sensory experiences through plantings and soil experiments are guiding the design process where the goal is to initiate processes developing over time between natural material and architectural interventions.

We can term this as an *Emergent Design* (ED).

The ED presupposes both knowledge on soil, chemistry and plants and gardening skills and extra focus on how to guide the maintenance staff after handing over the 'project'. Whereas the biodiversity levels can be monitored by counting, the question on how humans perceive and experience the green out-door spaces is not yet examined by SLA. It also seems that an ED process demands the presence of the landscape architect after handing over the project if the ED is to become a success. This is a 'new' task for SLA normally only following up on projects after one and three to five years.

The SLA strategy of having a poly-disciplinary staff composition inhouse suggests a multi-disciplinary methodology aiming at giving SLA more control in obtaining their design-vision without having to negotiate design and methodology with external partners.

In example 2, Tarup-Davinde the design process can also be described as 'flat' following a long-term structure plan guiding both the citizen-driven activities and the lay-out of roads, paths and the terrain formation and the major plantings coordinated and controlled by TD. TD is solemnly in control of the biodiversity program guided by the ambition to obtain the highest number of species.

The methodology followed can in contrast to example 1. be described as a trans-disciplinary coordination and facilitation of natural and material processes and citizen-driven recreational and social activities. The structure plan forms the framework around an ongoing design process, between professionals and non-professionals, along with the objective to support diversity in form of biodiversity, social activities and landscape diversity, hence the aesthetics and spatial formation are by-products of the objectives highlighting the participatory aspect in the design process.

In this the Tarup-Davinde area reinvigorates an old park typology, the informal activity park, also known as the grove or terrain vagues,[21] in suggesting that the citizens to be designated an area for them to design it according to their social and sports activities as part of a minor towns park policy.

For their part SLA reinvigorates former practice forms of the landscape architect in emphasizing the time aspect in the ED, i.e., a landscape architectural project as a process of cultivation – a constant exchange between the natural processes and the landscape architect's ideas on the design. Such a practice presuppose knowledge on plant physiology, soil qualities and chemistry in landscape architectural practice, which landscape architects formerly obtained through practical experience with gardening and horticultural studies. At SLA they try to cover these knowledge fields by the way the design-teams are organized.

CONCLUDING

The two discussed Danish examples of current urban nature projects illustrate a shift in terminology from park policies to urban nature and a strong focus on biodiversity, which impacts how urban green spaces are argued and designed. Even though a shift in terminology the purpose of park policies described in 4 Danish key documents – to provide experience of nature conditioned by the urban situation – maintains.

In both examples the current ambition to support biodiversity impacts both how landscape architectural projects comes into being, by whom and the methodologies applied, suggesting both multi- and transdisciplinary design teams and methodologies. In example 2, Tarup-Davinde the role of the landscape architect was to make long term structure plan that had the authority to guide the spatial development, and robust enough to incorporate within the overall structure minor and less permanent design projects are undertaken as a transdisciplinary dialogue between other professionals and non-professionals. The Tarup-Davinde area can be argued a current example of the informal activity park also known as a Terrain Vagues.

In example 1, Herlev Hospital, the design ambition to create, 'landscape architectural projects characterized by an abundance of sensory experiences, recreation, and solving self-induced urban problems,[22] impacts the role of the landscape architect by re-invigorating former knowledge fields and practices by a multi-disciplinary staff composition and methodology and by focusing on design as an Emergent Design (ED) process. This suggests old 'new' tasks for the landscape architect to perform as to successfully guide the Emergent Design a constant cultivating dialogue with the project and the material processes is needed. Such as practice was previously normal in landscape architecture but is now renewed.

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HARMONIZING CLIMATE RESILIENCE: STRATEGIC PLANNING AND IMPLEMENTATION OF BLUE-GREEN INFRASTRUCTURE IN EUROPEAN CITIES

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INTRODUCTION

This article highlights some of the most significant blue-green infrastructure projects implemented in public spaces in two European cities – Prague and Vienna – while analysing the strategic approaches that have guided their development. Central to this discussion is integrating innovative blue-green infrastructure, which represents a critical paradigm shift necessary for sustainable urban development and climate resilience. As cities across the globe face escalating environmental challenges such as rising temperatures, more frequent flooding, and the impacts of climate change, blue-green solutions offer a promising pathway to healthier, more adaptive urban environments.

Over the past decade, in my experience educating politicians and public administration officials on urban climate adaptation, stormwater management, and the design of blue-green infrastructure, I have observed a recurring and often substantial gap between the ambitious goals set by municipalities and the realities of what is implemented in public spaces. This discrepancy is particularly pronounced in Czech cities, where comprehensive strategies often fall short of translating into practical, on-the-ground projects.

In May 2024, I had the opportunity to observe similar efforts in the Austrian capital of Vienna,[1] a city often praised for its progressive urban planning and environmental initiatives. This comparative perspective between Prague and Vienna adds valuable insights into how different cities approach the integration of blue-green infrastructure and how these strategies can influence the overall resilience of urban areas.

This article is part of a broader dissertation research focused on understanding these dynamics in Prague. By analysing both Prague and Vienna, this study seeks to offer a deeper understanding of the barriers and opportunities that exist in realizing blue-green infrastructure in public spaces, contributing to the wider discourse on sustainable urban development.

Blue-green infrastructure

Green and blue infrastructure is proven to play a crucial role in enhancing urban quality of life by offering recreational spaces, mitigating the urban heat island effect through cooling, and promoting biodiversity.[2] Numerous studies suggest that the removal of impervious surfaces, combined with the introduction of trees and other vegetation—including green facades—provides significant climate adaptation benefits, particularly in urban street environments.[3] Implementing green and blue infrastructure measures is challenging because it involves addressing multiple urban issues, such as green and open spaces, traffic and utility infrastructure, water management, and sewage systems, while coordinating with various stakeholders.[4] Greening initiatives face numerous obstacles, including administrative, technical, and legal constraints, as well as a significant lack of awareness and acceptance among local residents and stakeholders.[5]

PRAGUE[6]

Prague's Climate Change Adaptation Strategy

The review of Prague's conceptual planning documents includes an analysis of the city's *Climate Change Adaptation Strategy*[7] (2018), which outlines six specific objectives. However, only two of these objectives directly address urban adaptation through blue-green infrastructure: (A) adaptation to temperature increases, urban heat islands, and heat waves, and (B) adaptation to mitigate the effects of heavy rainfall, flooding, and long-term drought in the capital city.

The remaining objectives focus on areas such as energy efficiency, crisis management, sustainable mobility, and public education. The overarching goal of the strategy is to "reduce the vulnerability of the City of Prague to the impacts of climate change in order to ensure a high-quality living environment for its inhabitants in the future." Its vision emphasizes "increasing the city's long-term resilience and reducing vulnerability to climate change impacts through the gradual implementation of appropriate adaptation and soft measures, thereby ensuring the quality of life for residents."

Implementation and Project Categorization

To operationalize the strategy, the city has developed follow-up implementation plans, specifically the *Implementation Plan 2018-2019* and the *Implementation Plan 2020-2024*. These documents act as roadmaps, providing a detailed list of planned or completed actions, commonly referred to as the "project stack". Projects are divided into four main categories: blue-green infrastructure, grey infrastructure, environmental projects, and studies or conceptual frameworks.

As of 31 July 2022, the updated "project stack" for the implementation of Prague's adaptation strategy includes a total of 294 projects, of which 97 have been completed, with a combined value of CZK 10,272,461,315.[8] The majority of these projects fall within three main categories: (i) the revitalization of parks, green spaces, and the planting of greenery, (ii) the construction, restoration, and maintenance of trees and tree plantations, and (iii) the creation of water bodies, wetlands, and floodplains for rivers and streams. Notably, 83% of the total funding has been allocated to blue-green infrastructure projects and objectives.

Challenges in Transparency and Strategic Planning

Despite the city's efforts to monitor progress through regular reports, the transparency of results and financial allocations remains problematic. The reports do not offer a clear breakdown of annual expenditures or detail which types of projects received funding. Moreover, while the adaptation strategy aims to reduce Prague's vulnerability to climate change, a surprising discovery is that none of the 294 projects seem to have been specifically designed with these overarching goals in mind.

Instead, these projects were primarily district-level investment initiatives that would likely have been implemented even without the strategy. Due to their alignment with certain objectives of the adaptation strategy, they were later included in the strategy's project pipeline. Districts that applied for funding were subsequently awarded full or partial subsidies for these projects. Further research will explore the specific motivations that led districts to prioritize these projects.

VIENNA

Heatwaves in Vienna

Since Vienna is situated further south in Central Europe compared to Prague, its climate policies place a stronger focus on heat protection. Over the past 35 years, the average seasonal temperature in Vienna from May to September has risen by more than 1.7°C.[9] The city of Vienna faced a stressful climate in the years 2003 and 2004 when the health of its inhabitants was impacted by increased mortality due to heatwaves. "In 2003 at least 130 heatwave-related deaths in Vienna could have been avoided by prompt medical assistance and proper advice about how to cope with excessive thermal conditions".[10]
In the light of the climate change impact, the City of Vienna has started an initiative *The Vienna Urban Heat Island Strategy* (2011-2014),[11] which was updated in 2023. The strategy aims to implement effective measures to reduce the negative effects of urban warming. Key practical actions in planning and project design include (i) increasing the quality of green in streets and open spaces, (ii) greening and cooling of buildings, (iii) retaining more water in the city, (iv) shading open spaces and paths, (v) cooling public transport. Blue-green infrastructure features prominently in the first three areas of urban planning initiatives. The strategy is followed by *Vienna Heat Action Plan,*[12] which serves mainly as a communication tool for different stakeholders rather than a planning tool.

Action through climate change adaptation projects

The City of Vienna is actively addressing the climate crisis through various initiatives. In 2022, it adopted the updated *Smart Climate City Wien Strategy*[13] alongside with *Vienna Climate Roadmap*, building on the earlier climate protection programs *KLiP I* (1999-2009) and *Klip II* (2010-2020). Major climate adaptation actions include *Klimapionierstadt Wien* (2023-2028), *GreenDeal4Real – Improving the thermal comfort in mixed-use areas through cost-effective green infrastructure* (2020-2025). While the updated strategy itself does not explicitly focus on blue-green or green infrastructure, it promotes the expansion of green spaces and greening of buildings, particularly in the chapter on climate change adaptation, which aims to enhance the urban microclimate.
The specialized concept for greenery and open space expands upon the goals of STEP 2025 (2014)[14] and sets the direction for planning in the city. One of the objectives of this approach is rainwater management. Green spaces are categorized into 12 types, with general objectives and tasks laid out for each, alongside projections for 2025.

Sponge City

Vienna has embraced the *Sponge City* concept, aimed at retaining rainwater to support tree growth while reducing pressure on the sewer system. Since 2019, one frequently used solution involves planting trees in a structural substrate, also known as the *Stockholm system*, which provides each tree with 35 m³ of rooting space. This space is filled with compacted gravel and a mix of sand, clay, compost, and biochar, which serves as essential nutrients for the trees.
Rainwater management measures under this concept create surfaces that allow water to naturally trickle away or evaporate where it falls, cooling the air and alleviating strain on the sewer system. A porous water retention layer beneath roads and pavements ensures that water is stored and made available to nearby street trees, further enhancing urban cooling and sustainability.
The MA22 Department for Environmental Protection of the City of Vienna has recorded approximately 320 projects aimed at enhancing the cooling effect within the city.[15]

EXAMPLES OF BLUE-GREEN INFRASTRUCTURE IN PRAGUE AND VIENNA

Both cities demonstrate a proactive approach to integrating blue-green infrastructure. In Prague, a year-long study involved extensive fieldwork in urban streets, coupled with interviews with engineers, architects, and landscape architects. Similarly, Vienna underwent a concentrated one-month analysis of its built environment. The observations indicate that Vienna has greater expertise in large-scale urban projects, particularly through its "sponge city" approach. This strategy not only enhances urban resilience but also provides a broader range of ecosystem services compared to Prague's implementations. In Prague, blue-green measures typically deliver only one or two ecosystem benefits and often appear experimental in nature, lacking the comprehensive impact seen in Vienna's more mature and well-integrated projects. The six examples below are the most representative of blue-green infrastructure in both cities, categorized into city parks, city centre streets, and large-scale residential projects.

Park revitalization

Figure 1. Prague, Revitalization of Kněžská Louka (Priest's Meadow) Town Park. The revitalization has transformed the area into a high-quality urban space designed for relaxation and enjoyment by a diverse range of users. The central feature of the park is a paved gravel area, which is lined with large-format, light-colored paving to minimize overheating. Rainwater runoff from these surfaces is directed into a specially designed rain bed. This system incorporates varied terrain with both flat and depressed sections to capture substantial volumes of rainwater, even during heavy downpours. The gravel substrate facilitates gradual water absorption, ensuring that it remains accessible to the park's vegetation. Plants within the rain bed are chosen for their ability to tolerate both dry conditions and temporary waterlogging. In addition to its primary function as a leisure space, the park includes a small children's play area, reflecting the input received during the design process. (photo: Zuzana Havlinova, 2024)

Figure 2. Vienna: Climate-Adapted Redesign of Johann-Nepomuk-Vogl-Platz. The park is located in Vienna's Währing district, has undergone a climate-sensitive redesign, developed through collaboration with local residents, businesses, and community groups. The transformation introduces abundant greenery with new trees and plants, ample seating to encourage relaxation, and a water jet feature to cool the air. The revamped square includes a newly designated weekly market area with wide pavements for leisurely strolling and an additional tram stop for improved public transport access. The redesign incorporates the "sponge city" rainwater management system to enhance climate resilience. Underneath the square's paved surfaces, a layer of coarse gravel and finer, water-retentive materials creates a "sponge" that absorbs and stores rainwater. This system captures all surface runoff, including water from fountains and some roof runoff from market units, which would otherwise enter the sewage system. The stored rainwater is available to sustain the newly planted trees during hot summer periods, contributing to a cooler and more sustainable urban environment.[16] (photo: author, 2024)

Redesign of a city street in historical center

Figure 3. Vienna, Zollargasse Street Redevelopment and Climate Adaptation. The street, redeveloped in 2021, incorporates climate adaptation as a central focus. Mature trees approximately 25 years old and 10 meters tall, were planted immediately providing substantial shade. These so called XXL trees, with a 4-meter crown circumference, are complemented by two covered pergolas standing 3 meters high. The surrounding soil is left exposed to facilitate proper drainage. To enhance the microclimate, the pavement features three nozzles and three misters that create a cooling water stream in the pedestrian area. The project utilizes the "sponge city" concept for stormwater management. A natural gradient in the water feature produces a flowing water film, with excess water directed to perennial beds for plant use. The drainage system is adjustable for seasonal operation, allowing water contaminated by salt in winter to be diverted directly to the sewer, protecting the tree roots from damage.[17] (photo: author, 2024).

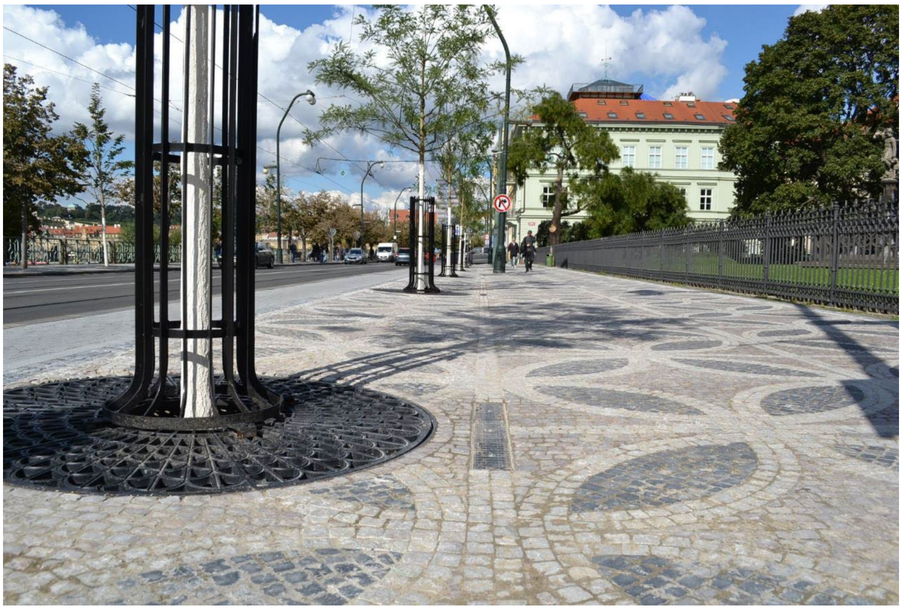

Figure 4. Prague, Smetana Embankment: Reconstruction of the Prominent Embankment with a View of Prague Castle. In 2022, the first phase of the Smetana Embankment redevelopment was completed, aiming to restore the waterfront's original promenade function, reminiscent of its role since the 1840s. The project enhanced the public space by widening sidewalks, adding a cycle path, and planting 17 Japanese knotweed trees. These trees are supported by a 200-meter-long underground soakaway system that collects rainwater from the 1,321 m² pavement area. The structural substrate used in the planting beds creates a 45 m³ retention volume, allowing for efficient water infiltration and promoting healthy root growth. This renovation exemplifies a modest yet effective transformation of a historic street into a blue-green infrastructure solution, integrating sustainable urban planning with improved environmental resilience. The figure shows the ground levelling towards the centre where the rainwater flows in. (photo: author, 2022)

New residential development

Figure 5. Prague, Modrany Sugar Factory (Modřanský Cukrovar): Pioneering Blue-Green Infrastructure in Czech Residential Development. A redevelopment of a former sugar factory brownfield, is the first multi-stage residential project in the Czech Republic to integrate comprehensive blue-green infrastructure. The project features a series of advanced measures designed to manage rainwater runoff and store it for future use, emphasizing water conservation as its primary theme. Green roofs in the development can retain up to 60% of rainwater, helping to cool the surrounding area through gradual evaporation and improving the local microclimate. Excess rainwater is collected in multiple storage tanks across the site, with a total capacity of 190,000 liters. This water is utilized for irrigating front gardens and community greenery in the courtyard. In the event of prolonged drought, boreholes at each stage of the development ensure the replenishment of water in the storage tanks, maintaining a minimal daily watering requirement. Overflow water is directed to retention facilities, and only when these are full is excess water released into the Vltava River. This integrated approach significantly enhances the site's resilience to climate variability while contributing to a sustainable urban microenvironment. The first out of six phases was finished in 2024. Photo: Skanska Reality visualization, 2023 (https://www.praha.camp/praha-zitra/projekt/modransky-cukrovar)

Figure 6. Vienna, Seestadt Aspern: A Pioneering Urban Development. Located on the former Aspern Airport site, Seestadt Aspern is Europe's largest urban development project, spanning 240 hectares. Launched in 2014, this "urban laboratory" is central to Smart City Vienna, featuring innovative ideas, concepts, and technologies. Designed to house over 25,000 residents and provide 20,000 jobs, Seestadt aims to blend high quality of life with environmental sustainability and economic innovation. The development includes multifunctional buildings, high-quality public spaces, and extensive green areas. Approximately 50% of Seestadt's area is dedicated to public space, with the remaining space featuring green zones and parks, guided by the internationally renowned Gehl Architects. Rainwater management follows the "sponge city" concept, incorporating a double drainage system across 22,000 m² of street area. This system enhances tree growth, improves the microclimate, and provides effective rainwater protection.[18] The picture shows one of the open space retention basin to slow down rainwater runoff.

CONCLUSION

This paper does not aim to provide a comprehensive comparative study but instead synthesizes findings from strategic document reviews and strategic process research over a 1.5-year period in Prague and Vienna. It incorporates insights from interviews with experts such as urban planners, landscape architects, and municipal representatives. The selected six case studies illustrate differences and similarities in implementing urban planning strategies.

Prague's approach is characterized by its detailed, concrete plans for implementation. While this precision ensures thorough planning, it can sometimes constrain creative solutions and dilute the sense of responsibility among stakeholders. Conversely, Vienna adopts a more adaptable, climate-sensitive approach that emphasizes well-established urban planning principles such as multifunctionality, public participation, and sustainable resource management. This flexibility provides urban planners and architects with more freedom and support in their work, facilitating innovative solutions and integrated strategies. The difference in these approaches could be partially attributed to Vienna's head start in incorporating climate adaptation into its urban planning framework, beginning nearly a decade earlier than Prague. This early adoption has allowed Vienna to develop a more mature and resilient model, showcasing the importance of foresight and the integration of established principles in addressing the multifaceted challenges posed by climate change in urban environments.

In both Prague and Vienna, the integration of blue-green infrastructure into urban planning has emerged as a crucial strategy for enhancing resilience to climate change. Vienna's advanced experience and systematic implementation of climate-sensitive principles, such as the "sponge city" concept, demonstrate the effectiveness of an adaptive, nature-based approach. Projects like Seestadt and the redesign of Johann-Nepomuk-Vogl-Platz exemplify how multifunctional spaces and integrated water management can significantly improve urban microclimates, provide recreational opportunities, and increase biodiversity. Prague, while making strides in adopting similar measures, often displays a more experimental approach, reflected in smaller-scale projects like Něžská Louka Park and Smetana Embankment. These efforts indicate a growing recognition of the value of blue-green infrastructure but also highlight the need for greater flexibility and stakeholder involvement. The comparison underscores the importance of a holistic, principle-driven approach to urban planning that not only mitigates climate risks but also enhances the quality of life in cities. For Prague to catch up with Vienna's progress, it could benefit from incorporating more flexible, principle-based frameworks that encourage innovation while maintaining accountability and public engagement.

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LOOSE-PARTS THEORY-BASED ANALYSIS OF URBAN SMALL-SCALE BIOPHILIC SPACES AND RESIDENT'S NATURAL CONTACT ACTIVITIES

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INTRODUCTION

In 2022, more than half of the world's population lived in urban regions. By 2050, over 75% of the world's population is estimated to live in cities.[1] So, more and more people have less chance to be in contact with nature due to the continuous expansion of urban areas[2] which leads to sustainability challenges affecting the environment, mental well-being and the society.[3]

To prevent urban residents from gradually becoming alienated from nature, leading to issues like the loss of natural experiences and nature-deficit disorder, cities need to provide more opportunities for urban residents to connect with nature. Biophilic urbanism emphasizes the creation of more and better biophilic spaces with a sense of place through ecological restoration and nature-friendly design.[4]

Academic research on nature contact has focused on three main areas: the characteristics of different types of nature contact, the measurement of differences in their effects, and biophilic design.[5] Types of nature contact can be classified according to an individual's life course into past and current contact; based on the mode of contact into direct contact, indirect contact, and symbolic contact; and according to the level of intentionality into incidental, accidental, and deliberate contact.[6] Some studies classify nature contact based on life contexts into everyday life scenarios and tourism scenarios, and further propose a theoretical framework called the "nature pyramid."[7] The above classifications are mainly from an objective perspective. However, recent research attempts to introduce embodiment theory, classifying nature contact based on human sensory experiences, including the five senses and holistic experiences. This type of research can better measure the individuals' subjective feelings.[8] Secondly, research on the effects of natural contact often focuses on its connection and benefits. It explores which types of nature contact can foster better connections with nature and generate more benefits. At least 16 different scales are used to assess the human-nature relationship. These measurement scales assess indicators from emotional, cognitive, and behavioural aspects.[9] The benefits of nature contact primarily include: improved mental health,[10] physical health benefits,[11] enhanced cognitive function,[12] social advantages,[13] developmental benefits for children,[14] and increased environmental awareness.[15] Building on the aforementioned research, studies in biophilic design delve deeper into the fundamental principles of biophilia, exploring why human beings need to connect with nature, identifying the types of natural elements that are most beneficial, and determining how spatial planning and design can enhance the effectiveness of these nature connections.[16]

Although existing research has demonstrated that simple exposure to nature alone is insufficient, and that establishing a psychological connection with the natural world is crucial for achieving lasting benefits, further in-depth exploration in this field is still necessary.

This study seeks to bridge the gap by providing an in-depth analysis of how various spatial attributes in different natural spaces influence the quality of nature contact and connections. Specifically, it investigates which small-scale biophilic urban spaces are most effective in promoting nature contact activities

, examining these processes at a micro level. The findings aim to deepen our understanding of the value and mechanisms of small-scale biophilic spaces, thereby enhancing the efficiency of nature contact in urban spaces in a cost-effective manner. The study first proposes two theoretical hypotheses:(1) The occurrence of nature contact activities is not evenly distributed across parks, streets, and buildings, but rather concentrated in specific small-scale biophilic spaces. (2) Different loose parts within these small-scale biophilic spaces facilitate nature contact activities.

Secondly, a qualitative research method was employed to conduct case studies on parks, streets, and buildings featuring abundant natural elements in Nottingham, UK, and Chengdu, China. One case for each type was selected in each city. The theoretical hypotheses were tested using walking observations, crowd activity observation records, and nature contact activity coding analysis. This process identified 12 types of "loose-parts

" that can promote nature contact activities in small-scale biophilic spaces.

This research method is based on firsthand observational data of nature contact activities, providing a more intuitive analysis of the distribution and interaction of these activities compared to traditional surveys and large-scale secondary data studies. Additionally, it encompasses various types of built environments across countries, offering more comprehensive insights.

However, due to constraints on research time and funding, the sample size for quantitative analysis does not encompass all seasons of the year. This limitation should be addressed in future research.

RESEARCH METHOD

Participants

This study was conducted by a team of five researchers, including two visiting scholars in the UK and three postgraduate students in urban and rural planning from China. The primary subjects of observation were residents active within the study area. The research began with a general survey of residents' activities, emphasizing nature-related activities during walking observations. Subsequently, specific timed observations were carried out in smaller biophilic spaces to categorize the types of activities. Over 15 residents were randomly selected for tracking and observation in each area, leading to a total of 170 valid observations.

Study sites and Walking Observation

During the preliminary research, the team identified several potential sites by analyzing data from online media hotspots. Following field visits and observations of the actual environments and patterns of human activity, six case study sites were selected, as shown in Figure 1.

The selection criteria were as follows: (1)Parks, streets, and buildings rich in natural elements; (2)Locations Primarily used for residents' daily activities; (3)Sites chosen based on social media analysis, interviews and on-site visits. These case areas represent, to some extent, parks, streets, and buildings with relatively high levels of natural contact in the two cities.

Figure 1. Six case study sites

Among these six case sites, the first step was to conduct walking observations[17] and identify small-scale biophilic spaces. From April to July, five researchers carried out intermittent and intensive walking observations at the study sites, with the most intensive observations scheduled on weekends. The observations were divided into three stages: (1) Exploratory Stage: Researchers explored the six sites, taking photographs to uncover and analyze implicit aspects related to the research, such as the frequency of natural contact activities across different areas of the sites. (2) Reflective Stage: Researchers reviewed the photographs and engaged in reflective analysis. They identified and marked areas with frequent natural contact activities on a satellite map. (3) Focused Observation Stage: Researchers conducted targeted walking observations in areas where natural contact activities were frequent. They meticulously recorded all observable activities during these observations.

Record individuals' activities

Building on the previously outlined observation classifications, record people's activities in small-scale spaces using the "Spatial Activity Observation Form." Follow these steps:
(1) Record Investigation Time and Weather Conditions; (2)Select Individuals Randomly: Observe individuals who cross the space boundary. Start observing the next subject only after completing the observation of the current one. (3) Record Personal Information: Include details such as gender and age groups of the individuals observed; (4) Categorize Activity Types: Record all activities, distinguishing between those involving natural contact and those not involving natural contact. Document each activity along with its direct object. Track the specific individual continuously marking off the corresponding activity types as they occur. Add any new activities as they arise. Record each action separately, without combining multiple activities.

Analyses

The data collected in this study includes maps of small-scale biophilic spaces driven from satellite imagery, a comprehensive list of activity types documented through field observations, representative photographs of various activities, lists detailing activity types among sampled populations, basic demographic information of the sampled populations, and data on the duration of activities at each site.

1. Statistical Analysis: Conduct a statistical analysis to determine the variety and number of activity types present in small biophilic spaces for each case study area. of natural contact, Identify natural contact activity types based on theoretical definitions, then analyze their proportions and calculate their occurrence frequencies.
2. Axial Coding: Utilize grounded theory to perform axial coding, categorizing human activities according to their characteristics related to natural contact.
3. Selective Coding: Apply selective coding to analyze the activity components associated with different types of natural contact activities, based on descriptions and corresponding photographs. Establish the relationships between these components.
4. Summarization: Summarize the activity components that contribute to the creation of small pro-nature spaces in the case study areas.

RESULTS AND DISCUSSION

The study identified 12 small-scale biophilic spaces across six case sites,cataloging the number of overall activity types, natural contact activity types, and thematic elements within each space. A comprehensive analysis was performed on a sample of 170 individuals, performed of 82 males (48%) and 88 females (52%). The age distribution was as follows: 63 individuals aged 0-12 (37%), 12 aged 13-17 (7%), 77 aged 18-64 (45%), and 18 aged over 65 (11%). The frequency of various natural contact activities was assessed, and the types of "loose parts" that facilitate these activities were identified.

Three types of natural spaces

Walking observation revealed that natural contact activities are not evenly distributed across the case areas. The spaces can be categorized into three types (Figure 2):
1. Non-accessible Natural Spaces: These include areas like deer habitats, lakes, dense forests, and maintenance buildings, where the frequency of nature contact activities is almost zero.
2. Accessible Nature Spaces: These are natural area that people can enter and experience immersively. While the frequency of natural contact activities is relatively high in these spaces, the variety of activities is limited, and the depth of interaction is often shallow. Most interactions involve walking on paths, observing the surroundings, or just occasionally resting.
3. Interactive Nature Spaces: These spaces feature specific natural objects or features that allow for deeper interaction and engagement, fostering stronger connections with nature. In these areas, both the frequency and variety of natural contact activities increase significantly. Activities such as digging, sliding down grassy slopes, and other forms of deeper engagement are common. These are typically small-scale biophilic spaces.
Understanding these distinctions helps identify which types of spaces are more effective at promoting meaningful nature contact activities.

Figure 2. Three types of natural space

In previous studies, these three types of spaces have often been uniformly classified as green spaces, without a more nuanced analysis. However, practical field surveys reveal that while the overall expanse of green spaces may be large, the areas that facilitate deep nature contact are relatively limited. Non-accessible natural spaces and accessible natural spaces generally offer a natural ambiance rather than actual opportunities for interaction. Therefore, the detailed analysis of the 12 small-scale biophilic spaces becomes crucial.

In these small-scale biophilic spaces, detailed observations and analyses uncover the specific elements and conditions that facilitate meaningful nature contact activities. This refined understanding highlights the limited yet valuable opportunities for deep nature contact within larger green spaces, underscoring the importance of designing and maintaining such interactive spaces in urban environments.

Types of activities and nature contact activities

In the small-scale biophilic spaces within the park in Nottingham, UK, 82 types of activities were observed, of which 42 were classified as nature contact activities, such as watching animals and sliding on grassy slopes (Figure 3). These nature contact activities accounted for 51% of the total activities. They can be divided into five categories, listed in descending order of frequency: animals, plants, water, natural spaces, slopes, and sky. On the street, 22 types of activities were observed, with seven classified as nature contact activities, such as sightseeing and walking dogs, representing 32% of the total activities. These activities fell into two categories, with the most frequent involving animals, followed by natural spaces. In the building, 17 types of activities were noted, 12 of which were nature contact activities, such as observing and touching animal models, comprising 71% of the total activities. These nature contact activities were categorized into four categories, in descending order of frequency: animals, artificial natural spaces, artificial natural facilities, and nature-related textual descriptions.

In the small-scale biophilic spaces within a park in Chengdu, China, 35 types of activities were observed, with 19 identified as nature contact activities, such as approaching the lake and swimming. These activities accounted for 54% of the total observed. The nature contact activities were categorized into seven categories, listed in descending order of frequency: animals, plants, water, natural spaces, artificial stones, sand, and sky.

On the street, 59 types of activities were recorded, with 29 classified as nature contact activities, such as gazing at the scenery and taking landscape photos, representing 49% of the total activities. These activities were divided into six categories, in descending order of frequency: animals, water, natural spaces, plants, stones, and sand.

In the building, 27 types of activities were observed, with nine being nature contact activities, such as observing and touching animal models, making up 33% of the total activities. These activities were grouped into four categories, listed in descending order of frequency: water, natural spaces, animals, and plants.

This comparative analysis provides insights into how different urban settings in Chengdu facilitate nature contact activities and illustrates how people interact with natural elements in parks, streets, and buildings.

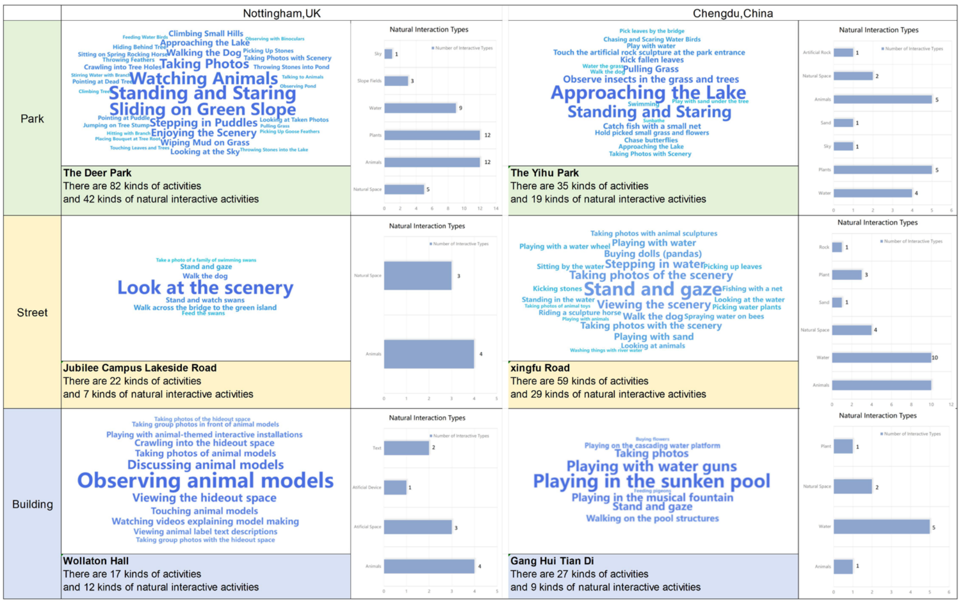

Figure 3. Word cloud of natural interactive activities and quality of activitiy types

People can engage in a variety of nature contact activities not only in parks but also on streets and within buildings. These activities often involve elements like water bodies, animals, plants, natural spaces, the sky, sand, slopes, and artificial objects, most of which encourage interaction. In parks, the most frequent activities are related to animals and plants, such as feeding water birds and hiding in tree holes. On streets, common activities include photographing animal statues and splashing water, focusing on animals and water features. In buildings, popular activities involve observing animal specimens and playing with water again highlighting the importance of animals and water elements.

In the UK, animal-related activities are particularly prevalent, whereas in China, water-related activities are more common. These insights help us understand the nature of everyday contact with natural world in these settings, facilitating a deeper analysis of the factors driving these activity. The findings emphasize the importance of designing urban environments that offer a variety of interactive nature contact opportunities, which can enhance the well-being of urban residents and foster a stronger connection with nature.

Categories of activities with loose parts

To rank the frequency of nature contact activities and identify the "loose parts" associated with the most frequent activities, we observed the following: In Nottingham, UK, parks had three types of loose parts, streets had two, and buildings had four. In Chengdu, China, there were five, six, and two types, respectively.

For example, in Little Deer Park (see Table 1), the most frequent water-related activity was "Stepping in Puddles." Analysis of representative photos revealed that the loose parts facilitating this activity consisted mainly of "naturally formed puddles + waterproof boots." Similarly, climbing plants was a common activity, facilitated by climbable wooden structures. Although some individuals were observed climbing natural trees, the high difficulty limited the frequency of this activity.

Categories	Activity Type	Frequency	Typical Photograph	Loose-Parts
Water (9 activity types)	**Stepping in Puddles**	**7**		Naturally formed puddles + waterproof boots
	Approaching the Lake	4		
	Playing with Simulated Rain Device	2		
	Throwing Stones into Pond	1		
	Pulling Grass and Throwing into Water	1		
	Pointing at Puddle	1		
	Observing Pond	0		
	Stirring Water with Branch	0		
	Throwing Stones into the Lake	0		
Plants (12 activity types)	**Playing on Wooden Climbing Frame**	**15**		Climbable wooden structures
	Wiping Mud on Grass	4		
	Playing on Wooden Seesaw	3		
	Crawling into Tree Holes	2		
	Hiding Behind Tree	1		
	Pointing at Dead Tree	1		
	Jumping on Tree Stump	1		
	Sitting on Spring Rocking Horse	1		
	Hitting with Branch	0		
	Placing Bouquet at Tree Root	0		
	Pulling Grass	0		
	Touching Leaves and Trees	0		
Sky (1 activity type)	Looking at the Sky	3		

Table 1. Loose parts in deer park and corresponding natural activity types

After analyzing nature contact activities and their corresponding loose parts in 12 small-scale biophilic spaces across six case sites, we identified 12 types of loose parts that correspond to four main types of nature contact.

1. **Observation Loose Parts:** These include diverse water features, a variety of flora and fauna, and video explanations. Unlike casual glances, this involves focused observation of natural objects or phenomena to gain deeper understanding and experience. The diversity of the loose parts is essential as it offers unique sights and details for observation. For example, a simple lake can present water plants, waterfowl, reflections, and ripples.

2. **Movement Loose Parts:** Examples include a sliding slope, climbable rocks and logs, and movable stones and sand. These loose parts encourage physical movement by adapting to human motion or providing natural objects that can be freely manipulated.

3. **Immersion Loose Parts:** These include features such as steps leading into a lake, a wading pool, and accessible hides. The primary characteristic of these parts is free entry, allowing people to immerse themselves in natural spaces. Designs like steps, waterproof clothing, and secluded areas facilitate this immersion.

4.**Communication Loose Parts**: These include friendly animals, virtual interactive devices, and other individuals participating in nature contact activities. Such parts enhance immediate feedback and promote continuous interaction through positive reinforcement.

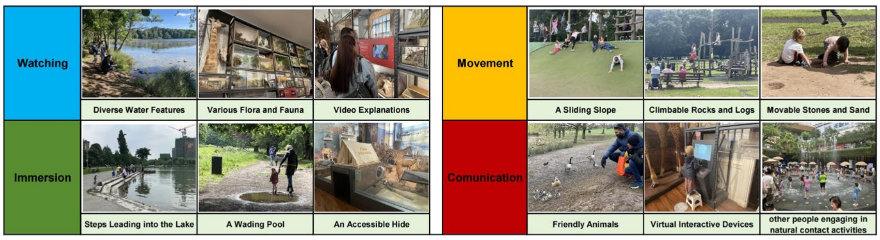

Figure 4. 12 loose parts with four categories of nature contact

CONCLUSION

This study examined the characteristics of small-scale biophilic spaces in urban environments and the factors that encourage nature contact. A qualitative case study approach was employed to observe and analyze nature contact activities in two parks, two streets, and two buildings in Nottingham, UK, and Chengdu, China. The research tested two theoretical hypotheses: (1) The occurrence of nature contact activities is not evenly distributed across parks, streets, and buildings, but rather concentrated in specific small-scale biophilic spaces. (2) Different loose parts within these small-scale biophilic spaces facilitate nature contact activities. The study identified 12 types of "loose parts" that effectively enhance nature contact activities in these spaces.

Related research builds on earlier studies of nature contact activities, enabling the further optimization of biophilic spaces in urban environments. This research aims to create more opportunities for nature contact, mitigate the negative effects of nature-deficit disorder on urban residents, and improve overall well-being. Future studies should include a greater number of case sites to explore nature contact loose parts in various cultural contexts, analyze their impact mechanisms on nature contact activities, and uncover the underlying patterns.

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FROM THE PUBLIC TO ENVIRONMENTAL EDUCATORS:AN EXPLORATION OF DRIVING FACTORS AND VERIFYING THE BIOPHILIA HYPOTHESIS

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INTRODUCTION

Biophilia theory posits that humans have an innate tendency to establish connections with nature and other organisms. However, the ongoing process of urbanization has led to an increasing separation between humans and nature, reducing active engagement in direct nature experiences. Exploring how individuals transform their interest in nature into the motivation to become environmental educators may help improve this situation. And how is this related to the biophilia theory? This study, grounded in grounded theory, conducted in-depth interviews with six environmental educators from diverse social backgrounds. It synthesized and explored the driving factors behind their choice to become environmental educators. These factors partly reflect individuals' motivations for engaging in nature education and interacting with natural environments. They contribute to bridging the gap between humans and nature, and providing validation for the biophilia hypothesis.

NATURE-DEFICIT DISORDER AND BIOPHILIA THEORY

The development of society is accompanied by a continuous reduction in urban green spaces.

It is concerning to note the widespread reduction in outdoor leisure for adults and outdoor play for children over the past few decades[1]. A significant contributing factor is the expansion of urbanization, with an unprecedented number of individuals now residing in urban centers. Cities are extensively altered, human-centric settings where green spaces have been diminishing over the years[2]. The estrangement between humanity and nature is also progressively intensifying. The shift in human activities from outdoor to indoor settings, coupled with reduced contact with nature, has engendered a sedentary lifestyle among individuals, precipitating a spectrum of physical and mental health issues. Children seldom have the opportunity to engage directly with the natural environment, which exacerbates their disconnection from nature, a phenomenon referred to as "nature-deficit disorder."[3]

However, the human instinct is to crave intimate contact with nature. The term "biophilia" was first proposed by the German-American psychologist and philosopher Erich Fromm in 1964, and professor Edward O. Wilson, a social biologist at Harvard University in the United States, extended and popularized this concept. In his book *Biophilia* mentioned, "Being close to nature is human instinct."[4]

Explains the inseparable connection between humans and nature from a biological perspective. In 1993, Edward O. Wilson and Yale University environmental psychologist Stephen Kellert jointly proposed the Biophilia Hypothesis, suggesting that contact with nature can have a positive and healthy effect on people's body and mind. [5]

NATURE CONTACT

Natural contact is a crucial component of the biophilia hypothesis and serves as a significant impetus for fostering harmonious coexistence between humans and the natural world. Contact with nature can have a positive impact on people's physical health, behavioral cognition, psychological adjustment[6] and adolescent growth, and can also promote people's protective behavior towards nature (Figure 1.).[7] At the same time, these factors are constantly narrowing the distance between people and nature and encouraging people to get in touch with nature.

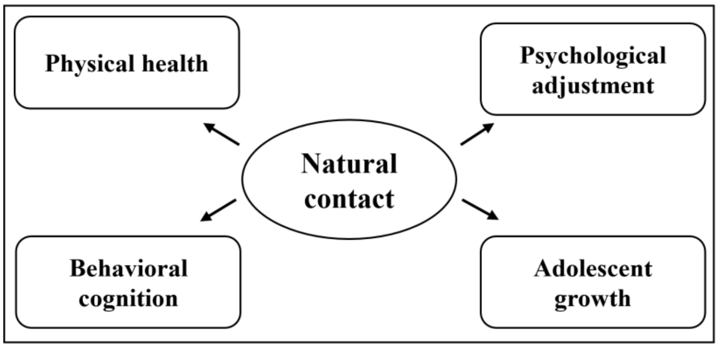

Figure 1. Four main effects of nature contact under biophilia theory

Research indicates that reduced contact with nature intensifies the sense of separation from it,which explains why people desire to connect with nature, even if through different means.[8] But even under the guidance of instinct, human contact with nature is still diminishing. How can we overcome the influence of the objective environment and close the gap with nature once again? Investigating the behavioral drivers of current nature interactors might help us find the answers. Based on the biophilia hypothesis, experts have proposed the 15 Patterns of Biophilic Design (Table 1.),[9] which are also hypothesized to be connected with the drivers of nature contact.

NATURE IN THE SPACE	NATURAL ANALOGUES	NATURE OF THE SPACE
1.Visual Connection with Nature	8.Biomorphic Forms & Patterns	11.Prospect
2.Non-Visual Connection with Nature	9. Material Connection to Nature	12.Refuge
3.Non-Rhythmic Sensory Stimuli	10. Complexity & Order	13.Mystery
4.Thermal & Air Flow Variability		14.Risk/Peril
5.Presence of Water		15.Awe
6. Dynamic & Diffuse Light		
7.Connection with Natural Systems		

Table 1. 15 Patterns of Biophilic Design

RESEARCH METHODS AND DATA COLLECTION

Research Methods

This paper selects Grounded Theory as the research method. Grounded Theory is a qualitative research method based on empirical information and theoretical construction proposed by American scholars Glaser and Strauss.[10] The researchers had no theoretical hypotheses before conducting the research. They started directly from actual observations, summarized the empirical overview from the original data, and then moved on to theory.

This study conducted in-depth interviews with environmental educators and open coding based on grounded theory, conceptualizing and categorizing the words, sentences and fragments of the interview data. Finally, based on the perspective of biophilia, a theoretical framework for the causes of environmental educators was proposed to measure the driving factors from the public to environmental education.

Data Collection

Educators are the most influential role models and agents of social change for young people and society at large.[11] They often have in-depth knowledge and exposure to their respective fields. Compared with those interested in the environment, environmental educators have a more direct and in-depth contact with nature. They have a strong desire to protect nature and maintain sustainable urban development, and hope to pass on this awareness to others. The ultimate goal of environmental education is to bring about action to solve current and future environmental problems.[12] Therefore, the analysis of the drivers of environmental educators can have a positive effect on promoting contact between people and the environment.

This study uses semi-structured interviews. According to Oliver C. Robinson's[13] Sampling in interview-based qualitative research, the sampling method follows the following four points. 1) *Sample universe*, to ensure the effectiveness of the interviews, the interviewees in this study were all environmental educators who had been involved in environmental education for 3 years or more. 2) *Sample size*, grounded Theory puts emphasis on being flexible about sample size as a project progresses.[14]The researchers collected data and analyzed it at the same time. When theoretical saturation was reached, the interviews were stopped.[15] In this study, theoretical saturation was reached when the number of interviews was 6. 3) *Sample strategy*, the method of selecting interviewees is mainly "purposeful sampling" in the "non-probability sampling" method. On the basis that the respondents were environmental educators, the selection of experienced environmental educators from different institutions and different regions ensured that there would be different or significant perspectives on the phenomenon discussed and its presence in the sample.[16] 4) *Sourcing sample*, the interview samples were derived from environmental educators that the researchers had come into contact with in recent years, and participants recommended by the interviewees were invited through *Snowball sampling.*[17]

The interview is immediate and dynamic, and the interview questions change flexibly with the situation. For example, if the interviewee mentions his past experience, it is necessary to supplement the details and feelings of the experience that have had a profound impact. The interview includes basic information such as the interviewee's institutional unit, years of engaging in nature education activities and natural education form (Table 2). The interview time for each person is 25-35 minutes. During the interview, the interviewee's answer was confirmed many times, and new information on related topics that emerged from the interviewee's conversation content was expanded. The interview was completed through offline interviews or telephone interviews. The interviewers all understood and agreed that all information in the interview would be used for academic research. The data will be processed in a timely manner after each interview, and the number of interviews will be determined based on the principle of topic saturation.[18]

INSTITUTION	AGE	EDUCATION LEVEL	YEARS OF ENVIRONMENTAL EDUCATION	ENVIRONMENTAL EDUCATION
Wild Things	52	Undergraduate	26	Offline
Green Youth	27	Undergraduate	5	Online+Offline
Green Youth	24	Postgraduate	3	Online+Offline
CFIF	42	Postgraduate	4	Online+Offline
SAU	40	PhD	3	Offline
Industrial City	41	Postgraduate	5	Online+Offline

Table 2. Basic information of the respondents

RESEARCH RESULT

Open Coding

Open coding requires researchers to break up and decompose all collected data with an open mind, give concepts, and recombine new concepts in new ways. This paper uses MAXQDA 2022 software to encode data, and some of the codes are shown in Table 3. Through the coding of the screened valid comment data, a total of 253 nodes, i.e., concepts, were obtained. These concepts are a summary and refinement of the content of the comment data.

Data location	Original interview text	Coding	Categorization
2024.5.17 K, Location 29	I could feel like I wasn't being watched by, you know, any male gaze, or I felt like I could just be, be be myself totally.	Self-value identification	Positive Feedback
2024.5.17 K, Location 15	Yeah, I visited the camp, decided to say it was a very beautiful woodland, and the people seemed really inspiring.	Support from others	
2024.5.12 Y, Location 7	There was a lot of rubbish, so we agreed to go pick up rubbish together next weekend.	Activities with others	Collective Participation
2024.5.17 K, Location 61	And fortunately, the team will all love each other. And we all love the work.	Collaborative work	
2024.7.1 L, Location 9	Many plants have some magical functions and can be used as medicine to bring benefits to people.	Understanding plant functions	Knowledge Exploratio
2024.7.1 L, Location 9	and then I will use my mobile phone to search for such plants.	Explore plant knowledge	
2024.5.12 Y, Location 15	after it rained, we and the other children would go to the puddles in the field and swim around	Playing in the rain	Favorable Timing
2024.5.17 Kate, Location 15	Easy to go on walks	Easy to go on walks	
2024.5.17 Kate, Location 57	And I used to be allowed to just run wild with my cousins and my brother. And it gave me a lot of opportunity to just be free outside.	Childhood Exploring nature with others	Childhood Experiences
2024.5.12 Y, Location 15	I loved rolling around in the ground, running wild, and often going to the fields to play.	Childhood nature interaction	

Table 3. Open coding Note: Due to the size of the sample, only part of it is shown.

Through the process of inductive reorganization of concepts, 16 categories have been identified: Personal Interests, Value Perception, Knowledge Exploration, Positive Feedback, Personal Growth, Collective Participation, Favorable Timing, Childhood Experiences, Environmental Actions, Direct Contact, Witnessing Harm, Desire for Change, External Support, Past Experiences, Encountering Difficulties, and Personal Beliefs. Due to the large amount of text, the above table only shows part of it.

Spindle encoding

The purpose of axial coding is to clarify the various concepts and their interrelationships, integrate higher-level abstract categories through repeated thinking and analysis of the relationships between concepts, and determine the nature and dimensions of related categories.[19] By further sorting out and summarizing the interview data and the concepts and categories extracted from the above table, a total of 5 main categories were summarized.The category Personal Development includes the subcategories of Personal Interests, Personal Growth, Positive Feedback, and Value Perception. Collaboration encompasses Collective Participation and External Support. Life Experience covers Past Experiences, Childhood Experiences, Direct Contact, and Personal Beliefs. Facing Challenges involves Encountering Difficulties, Witnessing Harm, and Desire for Change. Finally, Positive Actions comprises Knowledge Exploration, Environmental Actions, and Favorable Timing.

Selective coding

Selective coding is the process of further summarizing axial coding, with the aim of extracting the core category and linking the categories identified in axial coding to this core category. [20]Its objective is to connect the categories identified in axial coding to a core category that embodies the central theme of the research. The core category identified in this study is the driving factors for environmental educators. Its relationship with the various main categories is illustrated in Table 4.

Relationships	Implications
Personal Development	Personal development is a crucial factor influencing individuals' decision to become environmental educators, closely tied to their values and pursuit of goals.
Collaboration	Collaboration is a driving factor in individuals' decision to become environmental educators, as the involvement of others provides motivation for environmental educators.
Life Experience	Life experiences are key in shaping environmental educators' interactions with and understanding of nature. Their upbringing and experiences in learning and work deeply influence their attitudes and behaviors toward the environment.
Facing Challenges	Facing challenges drives environmental educators to address environmental issues, deepening their understanding and motivating them to take action.
Positive Actions	Positive actions are the result of influences from other main categories. Under favorable conditions, they provide practical support for becoming an environmental educator.

Table 4. Relationships and implications

Theoretical Saturation Check

Typically, theoretical saturation is reached when the existing data and the concepts, categories, and theories derived from them can sufficiently explain the research objectives or questions. During the final interview, no new categories emerged. Even after conducting two additional interviews, no new categories beyond the existing five were found. Therefore, it can be concluded that the theoretical relationship model between the current main categories and the core category is saturated.

DRIVING FACTORS AND BIOPHILIA THEORY

Driving Factors With Biophilic Pattern

The driving factors for environmental educators refer to the various motivations and influences that lead individuals to engage in environmental education. These factors include personal development, collaboration, life experiences, facing challenges, and positive actions.

In interviews with environmental educators, we can discover the convergence between the biophilic drivers of environmental education and the principles of biophilic design through dialogue. For instance, interviewees might say, "I looked up and saw a bird, which made me think of..." or "Every day when I return home, I can see the ginkgo trees on the street...". These statements confirm the biophilic pattern of Visual Connection with Nature within the NATURE IN THE SPACE category. Some interviewees mentioned, "I splashed in the rain with my friends," which corresponds to the Presence of Water; others recalled the tactile impressions of animals and plants from their childhood, aligning with the Material Connection to Nature pattern in NATURAL ANALOGUES. In a particularly memorable conversation, one interviewee said, "I lived on a tree trunk with my friends, like it was a temporary shelter," which perfectly corresponds to the Refuge pattern in NATURE OF THE SPACE. Biophilic design patterns, as a distillation of design approaches under the biophilic perspective, represent the essence and quintessence of the biophilia hypothesis. The driving factors reflected in interviews with environmental educators corroborate the hypothesis's portrayal of the relationship between humans and their environment. These patterns are grounded in the innate human affinity for nature, which is posited by the biophilia hypothesis to influence our well-being and behavior .

Driving Factors With Natural contact

Combining the driving factors with the four main effects of nature contact under Biophilia Theory reveals that Biophilia Theory can explain why these driving factors impact environmental educators (Figure 2).

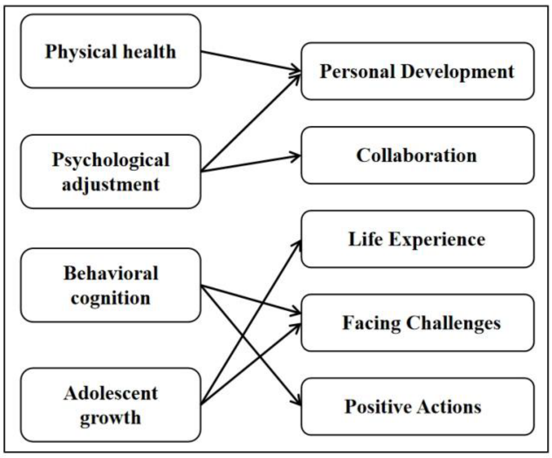

Figure 2. Four main effects under biophilia theory with driving factors

(1) Personal Development: The intrinsic interest in the natural world and the ability to recognize its value are key drivers in the development of environmental educators. This growth aligns with the Biophilia Hypothesis, which posits that our connection to nature plays a significant role in shaping both our physical and psychological development. The hypothesis suggests that humans have an innate tendency to seek connections with nature, and this tendency is reflected in the passion and dedication of those who educate others about the environment.

(2) Collaboration: The act of coming together as a community and receiving support from external sources is a powerful motivator for individuals to engage in the protection of the natural environment. This collective effort underscores the fact that the bond between humans and nature is not merely an individual affair but one that necessitates the support and active involvement of others. This collaborative spirit is a testament to the Biophilia Hypothesis, which posits that humans have an innate need to connect not only with nature but also with other living beings, fostering a sense of shared responsibility for the environment.

(3) Life Experience: The formative experiences of childhood, as well as past encounters and ongoing opportunities for direct interaction with nature, are crucial in establishing the profound influence that the natural world can have on an individual's development. These experiences, often rooted in childhood, lay the foundation for a lifelong relationship with nature, which continues to influence their environmental attitudes and behaviors as they mature. This ongoing process of engagement with nature supports the Biophilia Hypothesis, which suggests that our early interactions with the natural world are instrumental in shaping our environmental consciousness.
(4) Facing Challenges: The way individuals respond to environmental issues, the concern that arises after witnessing environmental harm, and the drive to effect positive change all reflect the deep and inseparable connection that humans have with nature. This connection is a central tenet of the Biophilia Hypothesis, which posits that humans are inherently linked to the natural world and are compelled to act in its defense. The hypothesis further suggests that this innate connection is what motivates people to confront and address environmental challenges.
(5) Positive Actions: The Biophilia Hypothesis is evident in the way nature influences behavioral cognition and the development of adolescents, as seen in the positive environmental actions that individuals take. This influence shapes their proactive attitudes towards environmental issues, encouraging them to engage in behaviors that support and protect the natural world. The hypothesis suggests that our innate affinity for nature is a powerful force that can drive individuals to act in ways that are beneficial to the environment, fostering a sense of stewardship and responsibility for the planet's well-being.

CONCLUSION

This study, encompassing in-depth interviews with a cohort of six environmental educators, delved into the pivotal drivers that inspire and propel individuals toward careers in environmental education. Concurrently, it validating the significance of the Biophilia Hypothesis in the human-nature relationship. Through a meticulous analysis and synthesis of 253 coded narratives, the study extrapolated five seminal determinants of human-nature interaction that demand scholarly attention: personal development, collaboration, life experiences, facing challenges, and positive actions. In the realm of personal development, establishing a sense of long-term goals alongside the dissemination of immediate, learnable environmental knowledge can foster public awareness and instill environmental values. Regarding collaboration, it is essential to actively promote community and school activities with strong operability to enhance public engagement and achieve shared environmental goals. Life experiences can be enriched by incorporating immersive field studies and outdoor education programs into the curriculum, thereby linking individuals' actions to environmental outcomes. Facing challenges should involve challenge-based learning that addresses current environmental issues, promoting resilience and problem-solving skills to confront the complexities of the environment. Lastly, positive actions can be encouraged by emphasizing success stories and providing opportunities for individuals to practice and internalize eco-friendly behaviors in their daily lives.These integrated approaches aim to cultivate a society that is not only knowledgeable but also emotionally invested and actively engaged in environmental conservation.
The biophilic drivers, uncovered through these interviews with environmental educators, act as the subterranean motivations prompting human interaction with the natural world. They are found to be in concordance with the axioms underpinning the 15 patterns of biophilic design, thereby corroborating their efficacy. This design paradigm acknowledges the profound human aspiration for connection with nature and demonstrates the potential to integrate natural elements into the fabric of urban planning, thereby bridging the chasm between humankind and the natural environment.

Furthermore, the study affirms the salutary effects of nature on physical well-being, behavioral cognition, and psychological adjustment. It also underscores the pivotal role of childhood encounters with nature in nurturing adolescent development. It is our aspiration that the findings of this research enhance the scholarly comprehension of the catalysts steering individuals toward environmental education and provide illuminating perspectives for the optimization of human-nature interactions.

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Resilient Cities in a Changing World: Design and the Urgency of Climate Challenge

Edited by Ian Owen.

Dr. Ian W. Owen is an architect, lecturer and researcher specialising in architectural pedagogy, computational design, and the cultural, historical and design aspects of postwar Welsh architecture. He is the Program Director for the Master of Architecture (MArch) at the University of Salford and a member of the Architectural Archives Advisory Panel for Wales (RSAW), advocating for the preservation and interpretation of Wales's architectural heritage. His recent publications include Diffusion Models and Architectural Education (AAE Conference, 2023), Safe Houses: Potentials and Limitations (12th International Urban Studies Conference, 2023) and Resilient Communities: A Novel Workflow (Frontliners in Built Environment, 2022), with a forthcoming book, Histories of Housing - Contemporary Housing from a Historical Perspective (Cambridge Scholars Publishing 2025).

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