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URBAN PLANNING

Volume 10

2025

Co-Creation With Emerging Technologies to Address Climate Challenges in Cities

Open Access Journal
ISSN: 2183-7635

Edited by Cesar Casiano Flores,
A. Paula Rodriguez Müller, and Evrim Tan

Urban Planning, 2025, Volume 10
Co-Creation With Emerging Technologies to Address Climate Challenges in Cities

Published by Cogitatio Press
Rua Fialho de Almeida 14, 2º Esq.,
1070–129 Lisbon
Portugal

Design by Typografia®
http://www.typografia.pt/en/

Cover image: © United Nations Information Centres from Flickr

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Available online at: www.cogitatiopress.com/urbanplanning

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Urban Planning
2025 • Volume 10 • Article 10809
https://doi.org/10.17645/up.10809

EDITORIAL

Open Access Journal

Towards Generative Governance: Co-Creation With Emerging Technologies to Address Climate Challenges in Cities

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Submitted: 13 June 2025 **Published:** 29 July 2025

Issue: This editorial is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

This thematic issue explores how co-creation processes, facilitated by emerging technologies, can help cities in addressing complex climate adaptation challenges. Drawing on seven interdisciplinary contributions, this issue examines the roles of digital tools, participatory methods, and institutional innovations in fostering inclusive and collaborative governance. The contributions highlight diverse approaches, ranging from computational planning support systems and interactive lighting simulations to community-based toolkits and scenario evaluators, that are implemented across various urban contexts. Collectively, they reveal both the opportunities for and the tensions of integrating emerging technologies into co-creation processes. This editorial identifies four key enablers of co-creation as generative governance—interactions, tools, processes, and institutions—and offers directions for future research at the intersection of digital innovation, collaborative governance, and climate adaptation. Together, the contributions provide a deeper understanding of how cities can design and support co-creation initiatives that are inclusive, adaptive, and capable of building long-term capacities to address climate change challenges.

Keywords

cities; climate adaptation; co-creation; digital tools; generative governance

1. Introduction

Cities around the world are facing the growing impacts of climate change (Casiano Flores et al., 2023; UN-Habitat, 2024). Consequently, cities have been taking the lead in developing strategies to facilitate adaptation and boost resilience (Mehryar et al., 2022). These strategies often rely on approaches to collaborative governance that are context-sensitive and forward-looking, enabling cities to adapt and build resilience effectively. As part of these approaches, co-creation has gained traction as a governance strategy that mobilises local expertise and fosters innovation through shared problem-solving (Torfing et al., 2019).

Co-creation refers to the collaborative process among public, private, and civil society players for solving shared public problems or completing shared tasks. This process involves exchanging resources to co-initiate, co-design, and/or co-implement visions, strategies, policies, regulatory frameworks, or technological solutions (Hofstad et al., 2022; Rodriguez Müller et al., 2025). Co-creation is increasingly recognised not only as a participatory method but also as a governance strategy, particularly well-suited to address complex and uncertain societal challenges.

In the context of climate adaptation, co-creation holds the promise of grounding solutions in local realities, enhancing legitimacy, and enabling continuous learning. However, there is still a limited understanding of how co-creation can happen when using emerging technologies, which may empower new forms of participation but also result in exclusion or asymmetries (Rodriguez Müller et al., 2021; Tan & Rodriguez Müller, 2024). This requires an analysis of how emerging technologies can support co-creation and participatory governance models (Rodriguez Müller et al., 2024).

To understand the academic landscape on this topic, we conducted a search on Scopus, combining terms related to co-creation, emerging technologies, and climate challenges in urban contexts. This search identified 41 relevant documents, with a sharp increase in publications over the last decade. The countries contributing most to the identified research include Australia, Austria, Germany, Spain, and the United Kingdom, with the European Commission emerging as the main funder. While this confirms strong interest in Europe, the dynamics explored are highly relevant globally, especially as cities worldwide seek to integrate inclusive innovation into climate governance.

This thematic issue, "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities," contributes to the growing field of research in this area. It provides both empirical and conceptual insights into how digital tools, participatory methods, and innovative institutional approaches can work together to support urban climate adaptation. It also outlines directions for future research at the intersection of co-creation, emerging technologies, and climate adaptation.

2. Contributions to the Thematic Issue

The contributions to this thematic issue offer rich empirical and conceptual insights into how co-creation processes, coupled with emerging technologies, are being mobilised to address climate-related urban challenges. Together, they explore the promises and tensions of embedding digital tools into participatory governance processes across diverse urban settings.

Five of the contributions focus on specific urban cases in Europe—occurring in the Netherlands (Chiappini & Coenen, 2025), Austria (Forster et al., 2025), Poland (Cudzik et al., 2025), Slovenia (Jukić & Vrbek, 2025), and Finland (Votsis et al., 2025)—while the remaining two adopt a broader urban approach that can be applied beyond specific European national contexts (Nath, 2025; Vermeulen et al., 2025). In terms of methodologies, the contributions reflect interdisciplinary and multidisciplinary approaches that combine qualitative methods, such as interviews, with quantitative methods, including computational modelling, surveys, and scenario simulations.

The contributions cover a wide variety of co-creation tools: a web-based tool for transformative community-based climate change adaptation (Nath, 2025), a modular lighting optimisation algorithm (Cudzik et al., 2025), a computational planning support system (Votsis et al., 2025), a decision support model for assessing co-creation (Jukić & Vrbek, 2025), and an adaptive design evaluator for sustainable impact co-assessment (Forster et al., 2025). Across the contributions, emerging technologies support and enable co-creation. However, these tools do not operate in a vacuum. The surrounding governance and institutional settings deeply shape their transformative potential.

Nath (2025) presents a web-based, mobile-accessible tool that empowers under-resourced communities to take ownership of climate adaptation through inclusive decision-making. The tool serves as a boundary object, integrating local data and reflexive facilitation mechanisms to help navigate power asymmetries. Similarly, Cudzik et al. (2025) introduce an algorithmic framework that can help to optimise urban lighting by integrating user feedback into a co-creation process. In this case, technology is not just about efficiency; it is a medium for co-designing public spaces in ways that consider safety, environmental goals, and lived experiences. Meanwhile, Votsis et al. (2025) demonstrate how a computational planning support system can be adapted to reflect sociospatial complexity. They achieve this by enriching existing models with urban commons data and integrating the models into co-design workflows.

Other contributions also explore the institutional conditions needed to support co-creation processes. Jukić and Vrbek (2025) introduce a decision support model enabling public organisations to assess the co-creation processes involved in a city's climate initiatives. Their model acts as a practical tool for the organisations, encouraging them to critically reflect on their roles in co-creation initiatives, identify areas for improvement, and enhance their capacity as co-creators of future urban climate policies. In another contribution, Vermeulen et al. (2025) propose the creation of a transition planning office with the capabilities needed to institutionalise co-creation across urban subsystems. Drawing on experiences from urban transition management and strategic spatial planning, the authors advocate for sustained involvement in long-term planning and the linkage of short-term projects with long-term transition agendas.

The contribution by Chiappini and Coenen (2025) highlights the interplay between digital literacy and socio-spatial disparities. The authors argue that the efficacy of co-creation technologies is contingent not only on their design but also on the varying levels of digital literacy and trust in government among citizens. The scope of implementation, type of engagement with residents, level of digital literacy, and opportunities for co-creation activities are key elements in achieving a more inclusive outcome in digitalisation. Finally, Forster et al. (2025) present a flexible tool that enables sustainability co-assessments in medium- and small-scale projects, challenging the rigidity of standard certification schemes. The tool's integration of visuals, stakeholder feedback, and dynamic modelling exemplifies how co-creation and technological adaptability can converge in the early stages of project planning to foster sustainable outcomes.

3. Looking Ahead: Co-Creation, Technology, and the Path Towards Generative Governance

Amid growing uncertainty and urgency, cities are shifting away from linear, top-down planning models and towards more adaptive, participatory, and context-sensitive modes of governance that favour integrated approaches (Buylova et al., 2025). This shift is particularly evident in how urban actors respond to complex climate-related challenges. Covering diverse urban contexts, the contributions to this thematic issue shed light on how co-creation, often supported by digital tools and platforms, is being mobilised to experiment with participatory formats, develop context-sensitive solutions, and institutionalise more inclusive governance practices.

Recent studies have begun to frame this changing landscape as *generative governance* (Ansell & Torfing, 2021a, 2021b). Unlike traditional governance models, which aim to deliver predefined outcomes, generative governance focuses on creating conditions that foster innovation. It relies on four interdependent enablers: trust-based and productive interactions; creative, inclusive digital and material tools; structured yet adaptive co-creation processes; and institutional frameworks that foster experimentation and continuity (Ansell & Torfing, 2021b).

Below, we explore how the contributions to this thematic issue enrich our understanding of each dimension of generative governance, while identifying gaps and opportunities for future research.

3.1. Generative Interactions

The term “generative interaction” refers to the behavioural and relational dynamics among participants that enable creative collaboration, such as trust, mutual respect, and a shared aim to innovate. Several contributions to this issue demonstrate how co-creation can foster such dynamics, while also revealing the challenges of sustaining them in technology-enabled processes addressing climate challenges.

For example, the Bee Path Project demonstrates how community-driven processes can generate trust and sustained participation over time through adaptive feedback and reflection mechanisms. The model supports public organisations in identifying areas where co-creation is succeeding, thereby enhancing their capacity as co-creators (Jukić & Vrbek, 2025). Similarly, Chiappini and Coenen (2025) uncover the tensions that can emerge when actors with varying levels of digital literacy and divergent expectations and behaviour engage in co-creation. While digital technologies open up new spaces for engagement, they also risk reinforcing existing power asymmetries if inclusive facilitation strategies are not adopted. Therefore, to achieve behavioural change, it is important to embed the use of technologies in a trust-based co-creation process involving residents. In this context, Nath (2025) emphasises the importance of accessibility, usability, and the incorporation of local knowledge, as trust is also a product of iterative co-learning and inclusive design.

Future research could explore the specific mechanisms that help build and sustain generative interactions when co-creating with emerging technologies to address urban climate challenges. It could also investigate how power asymmetries affect collaborative creativity in tech-enabled processes, and what kinds of governance arrangements and facilitation practices best support long-term, trusting engagement among parties with diverse interests and competencies.

3.2. Generative Tools

Generative tools are the technological or material instruments supporting the creation of new knowledge, ideas, or solutions. Contributions to this thematic issue show how digital platforms, data-driven simulations, and interactive toolkits can expand the reach and quality of co-creation processes to support climate adaptation. The computational model presented by Votsis et al. (2025) can serve as a boundary object, facilitating collaboration among stakeholders. Similarly, Nath (2025) presents a mobile-accessible, web-based tool that integrates climate data and participatory features to democratise adaptation planning in under-resourced communities, to actively shape adaptation strategies. Furthermore, Cudzik et al. (2025) introduce an interactive tool that can allow residents to co-assess the impact of lighting scenarios, and provide feedback, to make urban planning practices more adaptive, inclusive, and ecologically responsible.

These cases raise important questions about how emerging technologies can be designed and deployed to empower a broader range of participants to combat urban climate challenges. What makes a tool truly generative, beyond technical functionality, when addressing environmental risks? How do digital tools shape the framing of climate problems, the co-creation of solutions, and the legitimacy of different types of knowledge in participatory processes?

3.3. Generative Processes

Generative processes are structured co-creation methods, such as design thinking, scenario planning, or living labs, that guide participants through joint exploration and the collective development of solutions. Several contributions in this thematic issue apply, identify, or propose the use of these processes to organise collaboration and support urban climate adaptation, showing how co-creation can be embedded in various planning and governance settings.

Forster et al. (2025) operationalise participatory evaluation processes within early design phases, facilitating continuous feedback loops among stakeholders. These processes encourage early and continuous engagement, helping to identify trade-offs and improve transparency and awareness of cooperation. Likewise, Vermeulen et al. (2025) reflect on how institutional scaffolding and process design develop together in long-term sustainability transitions. They offer a typology of co-creation instruments, including urban living labs and virtual transformation labs, grounded in urban transition management and conceptualised through long-term processes.

Despite showing promise, generative processes are not inherently inclusive or effective. Future research could examine how the design of technology-supported co-creation efforts affects participation, decision-making, and the prioritisation of outcomes when addressing climate challenges. How can generative processes strike a balance between providing structure and flexibility while leveraging emerging technologies and digital methods? What kinds of facilitation practices and institutional support are needed to ensure co-creation efforts lead to transformative action rather than tokenistic consultation?

3.4. Generative Institutions

Finally, generative institutions refer to the formal and informal infrastructures that support and sustain co-creation over time and across projects. These institutions can provide the stability, legitimacy, and adaptability needed to embed co-creation in broader governance systems.

Vermeulen et al. (2025) propose the creation of a dedicated transition planning office to coordinate cross-sectoral collaboration and maintain continuity across short-term projects. By integrating co-creation practices into strategic planning frameworks, the office aims to link short-term interventions to long-term urban transformation. Additionally, Votsis et al. (2025) show how computational planning and co-creation processes that involve formal institutions and bottom-up informal processes can facilitate a more comprehensive and accurate mapping of society's vulnerability to climate change. Moreover, the Bee Path project (Jukić & Vrbek, 2025) and the web-based tool created by Nath (2025) show that institutional support enables successful co-creation and innovation.

Together, these contributions underline the importance of designing institutions that are both stable and adaptive to support co-creation with emerging technologies in urban climate governance. Future research could build on these ideas and explore what makes a co-creation platform resilient and adaptable in the face of digital transformation and climate-related uncertainty. In addition, how do political cycles, administrative cultures, and funding models shape the long-term viability of generative institutions in this domain? Longitudinal and comparative research is especially necessary to understand how the institutions change and how they shape urban resilience trajectories over time.

4. Conclusion: From Innovation to Institutionalisation

The integration of co-creation and emerging technologies is not merely a technical matter. It is political, relational, and institutional. The relevance of these interlinkages has been acknowledged at the international level by the European Commission, the Organisation for Economic Co-operation and Development (OECD), and the UN through the lens of a triple transition (digitalisation, environmental sustainability, and social responsibility), and this is reflected in efforts such as the new European Green Deal and the G20 flagship initiative "Lifestyles for Sustainable Development" (OECD, 2023).

The contributions in this thematic issue show that innovation must be embedded in inclusive processes, context-sensitive tools, and supportive institutional structures. By embracing the principles of generative governance, cities can navigate the uncertainties of climate change, through implementing collaborative processes that are as dynamic and diverse as the challenges they face.

Future research could deepen our understanding of the interplay between the four dimensions of generative governance: interactions, tools, processes, and institutions. How do (digital) co-creation tools and methods reinforce or undermine trust and participation? What institutional configurations are most conducive to experimentation and long-term impact? And, critically, how can co-creation processes be designed not only to manage current challenges but also to *generate long-term capacities* for sustained and inclusive climate adaptation?

As this thematic issue highlights, the value of co-creation with emerging technologies lies not only in enabling innovation, but also in building the long-term institutional capacities and facilitating the inclusive processes and trust-based interactions needed to tackle climate challenges systemically. Moving forward, we invite scholars, practitioners, and policymakers to engage with the insights provided in this issue and contribute to the developing conversation on how cities can co-create a more just, inclusive, and climate-resilient future.

Acknowledgments

We want to express our gratitude to the authors for their original, timely, and insightful contributions to this thematic issue. We would also like to extend our acknowledgment to the editorial team, particularly to Tiago Cardoso. Their constant support and guidance were key to this achievement.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning
2025 • Volume 10 • Article 9217
https://doi.org/10.17645/up.9217

ARTICLE

Open Access Journal

Co-Creation in Automated Public Space Lighting Design: Enhancing Safety and Reducing Light Pollution

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Submitted: 24 August 2024 **Accepted:** 11 February 2025 **Published:** 14 May 2025

Issue: This article is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

Public space lighting in urban areas is a crucial issue linked to climate change in developed environments. It significantly influences aesthetics, functionality, and the sense of safety while also contributing to the problem of light pollution. However, addressing these challenges requires a balance between technical optimization and environmental considerations, which this study explores through an experimental approach. This study examines the application of advanced digital technologies in designing and optimizing public space lighting, particularly in parks. The focus is on presenting a modular algorithm as a foundation for iterative improvements rather than a fully comprehensive lighting design solution. The article presents an algorithm that iteratively determines the optimal number and placement of lamps based on expected lighting levels. While illuminance levels are considered, future extensions could include additional parameters such as glare, uniformity, and color temperature to meet professional standards. This method has significant potential for involving public space users in lighting optimization. The algorithm relies on expected lighting levels, which can be derived from standards and designer decisions. However, user expectations can also be incorporated into simulations. For instance, an interactive application could allow users to highlight under-illuminated or overly bright areas, contributing to a co-created desired lighting map. Lighting levels can be precisely calculated, yet users' subjective perceptions may be crucial in achieving soft, nature-friendly lighting. The article presents the algorithm and discusses the potential of designer-computer and designer-computer-user co-creation for human- and nature-friendly design. This modular framework lays the groundwork for future refinements by integrating professional input and addressing broader lighting parameters.

Keywords
agent-based modeling; co-creation in urban design; digital design technologies; lighting optimization algorithms; parks lighting design; participatory design; public space lighting; sustainable urban planning; urban lighting design

1. Introduction

This research explores the possibilities of co-creation through digital generative techniques, using an algorithm for arranging lighting in public spaces, particularly parks. While professional lighting design typically involves predefined standards and practices, this study adopts an experimental approach to explore modular solutions that can be iteratively refined and extended. As digital design technologies continue to advance, new forms of collaboration are emerging among participants in the design process. This collaboration can occur between designers and users. Generative techniques further enable cooperation between designers and digital tools, fostering innovative solutions to complex urban challenges like lighting optimization. Additionally, generative techniques enable multi-entity collaboration involving users, digital tools, and designers. This article will demonstrate the potential of applying such an approach to lighting design in public spaces, especially parks, to achieve user-friendly and environmentally sustainable solutions. Lighting is a crucial aspect of designing public spaces. It plays a significant role in ensuring safety by enabling obstacle avoidance and mitigating potential criminal risks (Cui et al., 2023). Well-lit public areas contribute positively to safety and night-time social activities (Chen et al., 2024; Rakonjac, Zorić, Djokić, et al., 2022; Rakonjac, Zorić, Rakonjac, et al., 2022). However, poorly designed or excessive lighting can lead to a range of issues, including glare, lack of uniformity, and light pollution. Light pollution is a rapidly increasing alteration to the natural environment that requires urgent attention (Cinzano et al., 2001). It disrupts ecosystems, affects human health, and contributes to unnecessary energy consumption. The correlation between light pollution and environmental changes is a subject of ongoing research (Falchi et al., 2016, 2019; Gallaway et al., 2010; Kocifaj et al., 2023). Addressing light pollution requires a multifaceted approach that considers illuminance levels and parameters such as luminous intensity distribution, shielding techniques, mounting height of luminaires, and color temperature. These factors significantly influence the environmental impact of lighting systems and their alignment with sustainability goals. Despite advancements in professional lighting software such as DIALux (DIAL GmbH, n.d.) and Relux (Relux Informatik AG, n.d.) that allow for detailed photometric simulations, there remains a gap in integrating these tools with participatory design processes (Kubiak, 2024). The proposed framework aims to bridge that gap and emphasizes flexibility through its modular structure while allowing for future extensions to include more advanced qualitative and quantitative criteria. The significance of this study lies in its potential to address two critical challenges simultaneously: enhancing safety in public spaces through optimized lighting design while minimizing environmental impacts caused by light pollution. This study contributes to developing human- and nature-friendly lighting systems that align with contemporary urban sustainability goals by leveraging co-creation processes involving designers, users, and digital tools.

2. Materials and Methods

The research method consisted of multiple steps in the diagram (see Figure 1). Step A1 of the research method involved analyzing algorithmic design and optimization techniques. The authors analyzed the variety of possible approaches to automated design, including evolutionary approaches (Frazer, 1995; Kamaoğlu, 2023; Nessel, 2017; Schumacher, 2015), strict rules approach (Cudzik & Nessel, 2024; Filipowski & Nessel, 2018), agent-based and iterative approaches (Mosteiro-Romero et al., 2024; Rahbar et al., 2022; Zargar et al., 2023), deep learning in architecture (Kafy et al., 2022; Rahbar et al., 2022; Zhao et al., 2022), as well as case studies (Mukkavaara & Sandberg, 2020; Pérez-Martínez et al., 2023; Rodrigues et al., 2015) and other complex approaches and comparisons (Aranburu et al., 2022; Assasi, 2019; Caetano et al., 2020; Cudzik, Nyka, et al., 2024; Cudzik, Unger, et al., 2024; Lee et al., 2014; Oleksy et al., 2022; Reitberger et al., 2024; Romaniak & Nessel, 2019; Schwartz et al., 2021; Sönmez, 2018; Zboinska et al., 2015).

The stages B1, B2, and B3 (see Figure 1) were focused on literature studies and analyses related to public space lighting, including light pollution (Falchi et al., 2016, 2019; Gallaway et al., 2010; Kocifaj et al., 2023), safety topics and correlations between user behaviors and light quality (Zielinska-Dabkowska, 2018). Another crucial aspect of public space lighting is its association with light pollution. Law regulations and studies of existing lighting in urban park area designs were also analyzed, formulating fundamental design problems, principles, and possible simplifications of the design task (see Figure 1, stage B4). One of the fundamental principles in programming is the Single Responsibility Principle (Martin, 2003).

On the other hand, solving design problems is instead a complex process. Therefore, a primary objective at stage B4 was to simplify the design task to the absolute minimum. While such an approach involves accepting certain shortcomings, it enables transparent testing that yields reliable results, even in the early stages of algorithm development. Many parameters should be evaluated when analyzing public space lighting quality. Based on analyses and the Polish norm, the required minimum illuminance level was identified as the most critical (Polski Komitet Normalizacyjny, 2007). Legal standards often specify different minimum illuminance levels for various uses of space (Polski Komitet Normalizacyjny, 2007). Therefore, in the context of public parks, the algorithm should accept at least two values of minimum illuminance level: for pathways and squares and separately for green areas. The authors stated that by operating on these parameters, the algorithm should suggest lamp positions so that the minimum illuminance criteria are achieved throughout the park. Critical parameters for calculating illuminance levels were identified as the luminous intensity and height of the light sources. To simplify the design problem, a uniform height and brightness were set for all light sources. Additional constraints and simplifications included assuming point light sources with uniform emission, ignoring shadows, and excluding light sources outside the study area.

At stage A2 (see Figure 1), based on the analyses and assumptions formulated in stages B4 and A1, it was decided that the algorithm would be developed using an agent-based approach. The algorithm was developed using industry-standard 3D design software, McNeel's Rhinoceros 8, and Grasshopper visual algorithm editor (Version Friday, 17th May 2024, Build 1.0.0008). Specific components were implemented using the C# programming language to enhance the algorithm's flexibility and functionality. The programming process was facilitated by Microsoft Visual Studio 2022, enabling real-time debugging and streamlined code maintenance. Subsequently, the algorithm was developed and cyclically tested to improve its functionality during stages C1 and C2 (see Figure 1). Initially, tests were conducted on hypothetical outlines. Later, the tests were conducted using actual, existing park locations to make the results more realistic. After analyzing potential test locations, Park Grechuty in Krakow, Poland, was chosen for further tests (see Figure 1, stage C3; Zachariasz, 2018). This selection was based on several factors: it is a publicly accessible urban park; it includes both green spaces and paths and squares; it has an irregular layout; it was

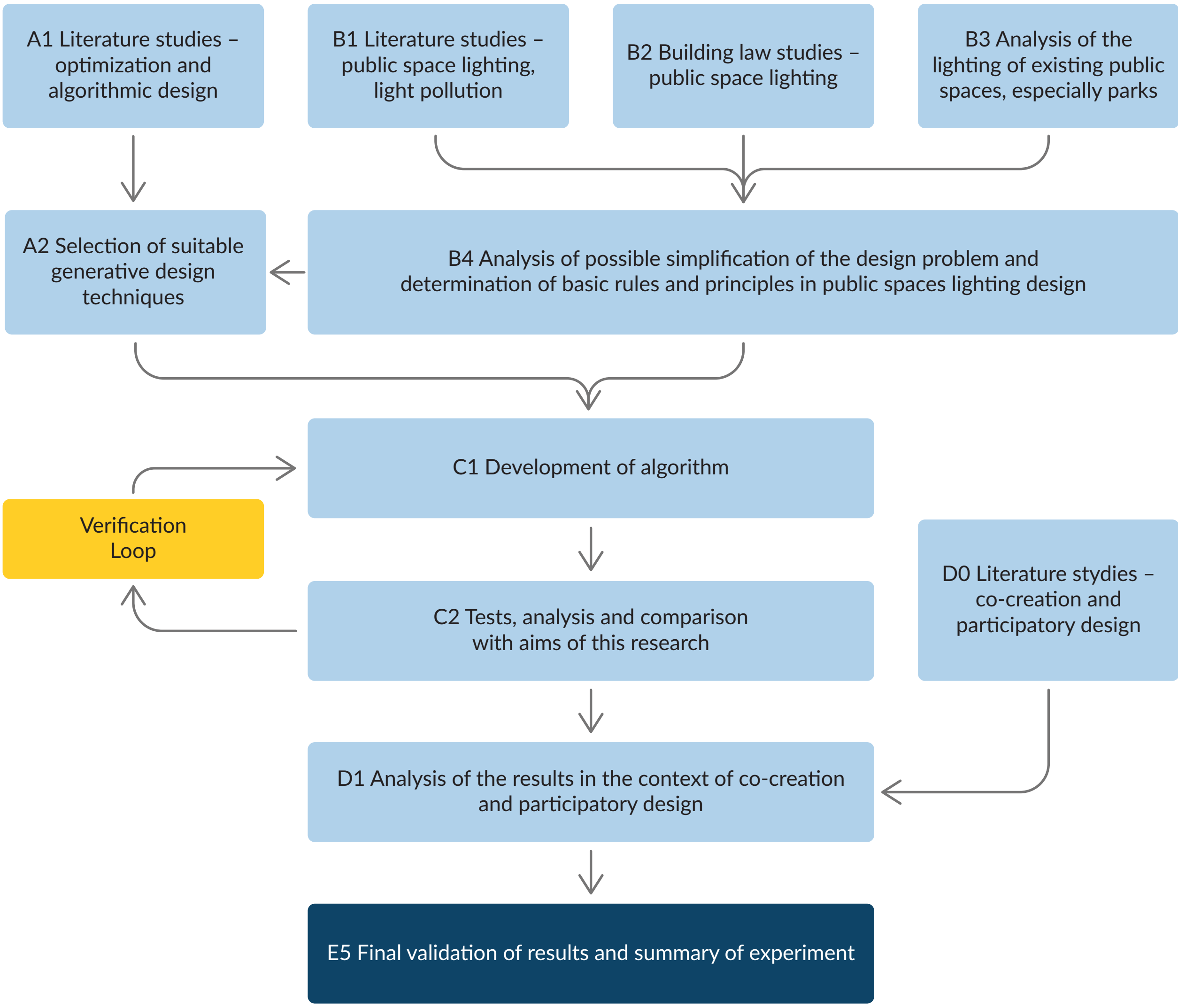

Figure 1. The research method diagram.

recently renovated, including the replacement of lighting; and it features relatively uniform lighting. This enabled the algorithm to compare its results with the park's existing lighting.

Tests were conducted with varying parameters, light source luminous intensity, lamp height, and the desired illuminance of surfaces. The algorithm's performance was analyzed through simulations based on the existing lighting solution. Both graphical and numerical data were collected for subsequent analysis during the tests. This facilitated the evaluation of the algorithm's results, its potential for automating the lighting design process, and its implications for sustainable design and light pollution. The analyses conducted at stage C4 indicated that the algorithm could be used in participatory design. This insight led to an expanded review of the literature and analysis in this area (Buongiorno Sottoriva et al., 2022; Jung & Kang, 2023; Kashem & Gallo, 2023; Lorens & Zimnicka, 2023; Rodriguez Müller et al., 2024; Smith et al., 2024; Zidar et al., 2017). The research findings were then discussed, and conclusions were formulated.

All literature studies (stages: A1, B1, B2, D0) were conducted using state-of-the-art methods combined with elements of the systematic search review methodology (Grant & Booth, 2009). As shown in Figure 2, they

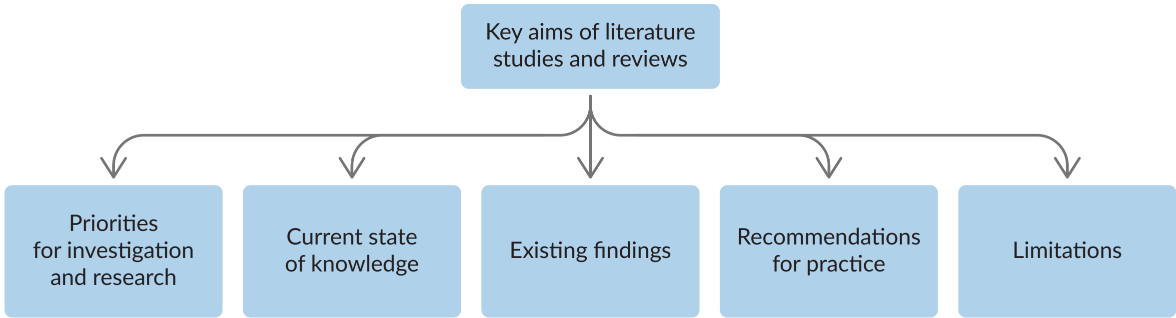

Figure 2. Key aims of literature studies and reviews.

focused on the current state of knowledge, priorities for investigation and research, existing findings, recommendations for practice, and limitations.

3. Algorithm

The algorithm developed in this study is designed to optimize the placement and luminous intensity of light sources in urban parks, ensuring that lighting conditions meet specific safety and usability standards. While the current implementation focuses on minimum illuminance levels, future iterations could incorporate additional parameters such as glare control, uniformity, and energy efficiency to align with professional lighting practices. The central concept of the algorithm is illustrated in Figure 3. It revolves around an iterative process that dynamically adjusts lamp positions based on real-time feedback from various test points distributed throughout the park.

The initial phase of the algorithm is of utmost importance as it lays the foundation for the entire simulation process. It involves preparing the fundamental data required for the simulation. This preparation includes generating a list of test points evenly distributed within the park boundary to measure illuminance levels at key locations (see Figure 4b). Each test point is assigned a minimum expected illuminance level based on its functional classification—whether it is located on pathways, squares, or green areas. This differentiation ensures that lighting requirements are tailored to specific park zones, reflecting real-world design standards. Concurrently, the initial positions of the lamps are uniformly generated within the park boundary (see Figure 4a). These lamps and test points are placed using a pseudorandom distribution, ensuring no direction is favored, thus allowing for a more organic and realistic simulation process.

However, this approach assumes uniform lamp characteristics (e.g., height and luminous intensity), simplifying initial testing but limiting its applicability to more complex scenarios involving diverse luminaires. Notably, the initial number of lamps is set to be lower than the anticipated final number, allowing the algorithm to add more lamps as needed during optimization. The core operation of the algorithm takes place within its main loop, where it iteratively refines the lamp positions to achieve the desired lighting conditions. Initially, the algorithm calculates the illuminance levels at all test points by applying the inverse square law of light attenuation, considering the contributions from all existing light sources (see Figure 4c). This calculation assumes point light sources with uniform emission patterns and does not account for factors such as shadows or variations in luminous intensity distribution. These simplifications will be addressed in future iterations to enhance accuracy. The calculated illuminance levels are then compared against the minimum

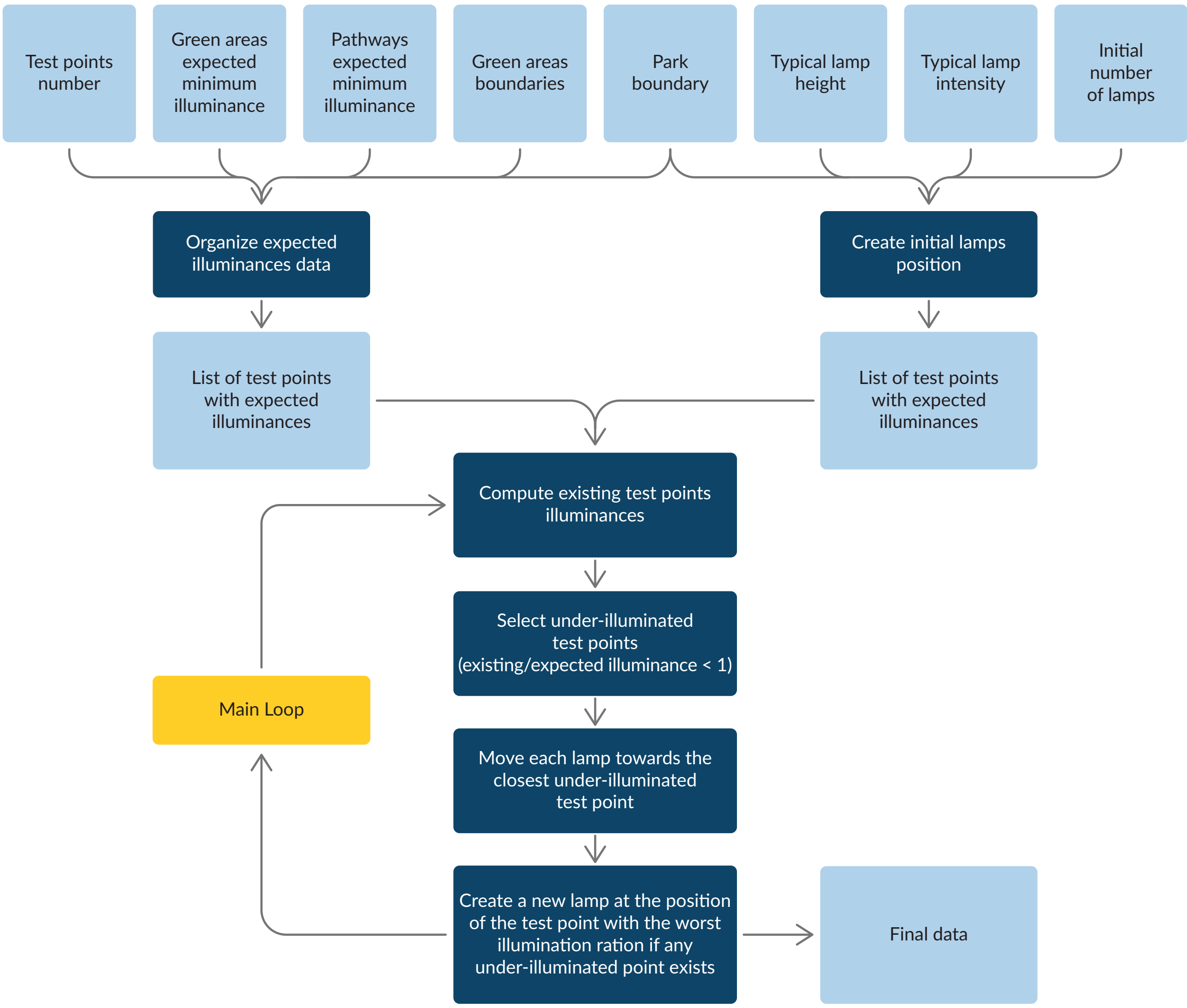

Figure 3. The algorithm diagram.

required levels at each test point to identify under-illuminated areas (see Figure 4b). Once under-illuminated points are identified, the algorithm adjusts the lamp positions. Each lamp is moved horizontally towards the nearest under-illuminated point, ensuring light is distributed more effectively across the park.

Additionally, the algorithm periodically introduces new lamps at strategic locations, specifically at test points where the disparity between actual and expected illuminance is most significant. The placement of new lamps considers their proximity to under-illuminated areas and their potential overlap with existing light sources to avoid redundancy and excessive energy use. However, adding new lamps is controlled and does not occur in every iteration; instead, it is performed at specific intervals to maintain a balanced and efficient increase in lighting coverage. The iterative loop continues until the algorithm achieves a state where no further test points remain under-illuminated, indicating that the park's lighting conditions meet or exceed required standards.

At this point, the algorithm outputs the final positions of the lamps along with computed illuminance values for all test points (see Figure 6). This output includes graphical representations such as false color maps and numerical data tables for detailed analysis. These results allow for secondary metrics to be computed—such

Figure 4. The initial state of simulation: a) initial positions of lamps, b) visualization of test points meeting the minimum illuminance criteria (orange samples) and being under-illuminated (dark grey samples), c) visualization of test points computed illuminance levels.

as average illuminance levels, uniformity ratios, and energy consumption estimates—to evaluate and compare different lighting configurations (see Table 1). Including these metrics provides a more comprehensive assessment of lighting performance beyond meeting minimum illuminance requirements. The entire process demonstrates the algorithm's capability to create a lighting design that is both functional and adaptable, capable of addressing diverse urban park environments' complex needs. While this study focuses on foundational principles and simplified scenarios, it establishes a framework that can be expanded in future research to include more advanced parameters and professional input from lighting designers or urban planners.

4. Results

The results of this study provide a comprehensive and nuanced analysis of the proposed algorithm's performance and effectiveness in optimizing public space lighting within an urban park setting. This analysis evaluates the algorithm's ability to meet minimum illuminance requirements. It explores its potential to address broader urban lighting objectives, such as reducing light pollution, improving energy efficiency, and enhancing user safety. Specifically, the study examines the algorithm's ability to balance multiple factors, including safety, energy efficiency, and environmental impact, while adhering to regulatory standards.

The results underscore how the algorithm's modular framework allows for iterative refinements and adaptability to different urban contexts. The analysis, structured around a series of carefully designed tests, compares the algorithm's outputs with the existing lighting configuration and delves into a range of alternative scenarios. These scenarios involve systematically adjusting parameters such as lamp height, luminous intensity, and expected illuminance levels. For example, variations in lamp height were tested to assess their impact on uniformity ratios and glare control, while adjustments to luminous intensity were

Table 1. Tests results.

Test Id	0	1	2	3	4	5	6
Lamp height [m]	10	10	6	6	6	6	15
Lamp light source luminous intensity [cd]	720	720	300	300	300	720	720
Lawn expected illuminance [lx]	1	1	1	2,5	1	1	1
Pathways expected illuminance [lx]	5	5	5	5	3,5	5	5
Total number of lamps	78	81	153	183	127	91	81
Average illuminance	4,864	5,152	4,378	5,151	3,627	6,291	4,776
Illuminance of brightest test point	14,697	12,164	14,406	13,667	11,961	24,998	8,426
Illuminance of brightest test point without top 20 samples (0,4%)	12,360	10,810	11,505	11,328	9,889	21,984	7,857

analyzed for their influence on energy consumption and light distribution. By exploring these variations, the study reveals how different configurations can influence the overall lighting quality, distribution of light across different areas, and the balance between brightly and dimly lit zones.

This approach highlights how professional lighting considerations—such as luminous intensity distribution curves and shielding techniques—can be integrated into future algorithm iterations for enhanced performance. This approach allows for a thorough evaluation of the algorithm's flexibility and robustness in addressing the complex challenges of urban lighting design, with direct implications for practical urban planning and lighting design. Furthermore, the study considers the implications of these adjustments for urban planning goals, such as reducing light pollution, enhancing nighttime visibility, and ensuring that public spaces are welcoming and secure. For instance, scenarios focusing on minimizing upward light emissions demonstrated how the algorithm could reduce light pollution metrics such as the Upward Light Ratio and Upward Flux Ratio.

The results highlight how the algorithm can be adapted to different urban contexts, catering to specific needs and preferences while maintaining compliance with established lighting standards. By providing a detailed breakdown of each test scenario, the study offers valuable insights into the practical applications of the algorithm in real-world urban environments, demonstrating its potential to significantly improve the design and management of public space lighting. This includes its ability to serve as a decision-support tool for planners by offering visualizations (e.g., false color maps) and numerical metrics that facilitate informed decision-making. The table presents the results of the final tests conducted in this research, including key input parameters and primary and secondary numerical data (see Table 1). Test 0 shows the illuminance levels computed by the algorithm using the current lamp positions (see Figure 5).

The emitter's luminous intensity, height, and expected illuminance levels are consistent with those in Test 1 (see Figure 6). In these two tests, minimum illuminance values reflect the Polish norm (PN-EN 13201:2007). This ensures that comparisons between existing solutions and algorithm-generated configurations are grounded in established regulatory standards.

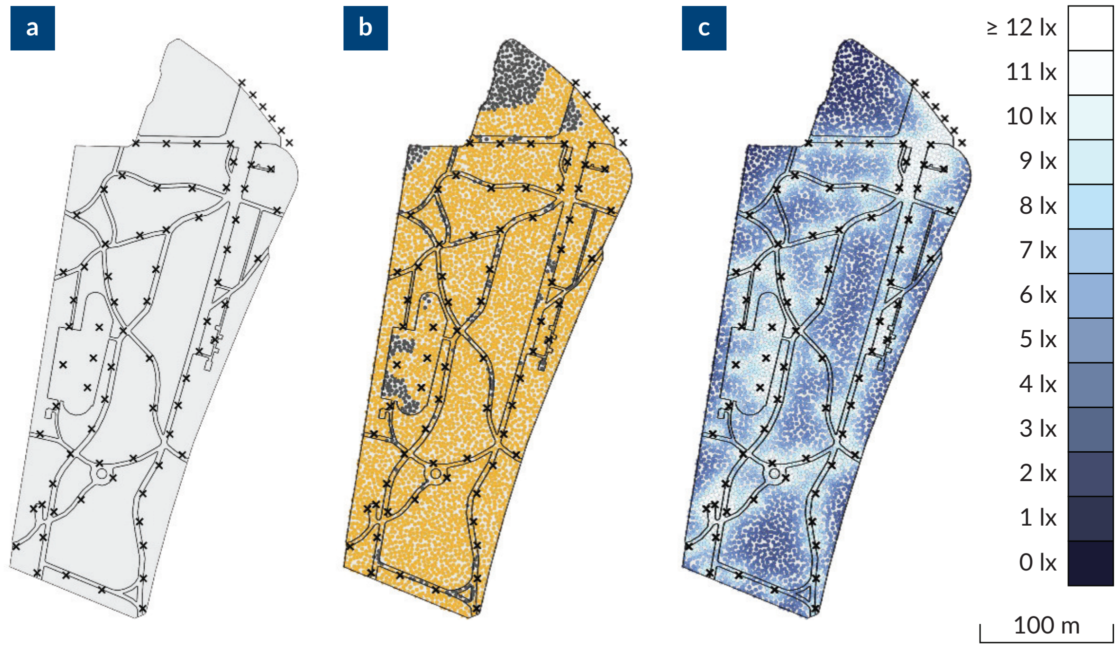

Figure 5. The visualization of theoretical illuminance using the existing position of lamps and the same settings as in Test 1: a) positions of lamps; b) visualization of test points meeting the minimum illuminance criteria (orange samples) and being under-illuminated (dark grey samples); c) visualization of test points computed illuminance levels.

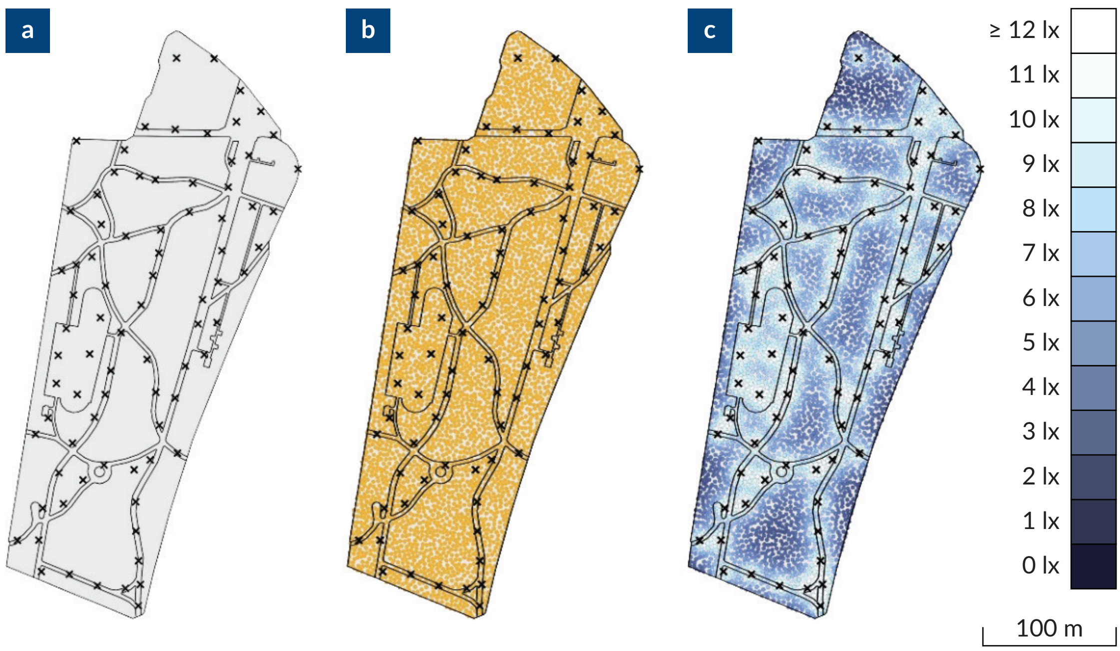

Figure 6. The final state of Test 1: a) positions of lamps; b) visualization of test points meeting the minimum illuminance criteria (orange samples), no occurrence of under-illuminated test points (dark grey samples); c) visualization of test points computed illuminance levels.

However, it is essential to consider the algorithm's limitations and resulting simplifications during these comparisons. For instance, assumptions such as uniform lamp characteristics (e.g., height and luminous intensity) or exclusion of shadows from obstacles may affect how closely test results align with real-world conditions. Additionally, to simplify testing, external light sources outside the park boundaries and the impact of park lighting on the surrounding area were excluded from calculations. However, these aspects could be incorporated into future iterations for greater accuracy. Despite these limitations, the results provide a strong foundation for further development of this approach.

As shown in Figure 5, some lamps in the existing solution are positioned outside the park boundary. They were included in Test 0 because they are essential for achieving the appropriate illuminance levels in the square in the park's northern part. Additionally, a pond within the park was omitted from the tests to simplify the problem. Although the existing lamps are similar, they are not identical; therefore, the height and luminous intensity values used in the computations are approximations of the actual conditions due to the algorithm's limitations.

Tests 2, 3, and 4 (see Figure 7) illustrate the algorithm's results using lower lamp heights and reduced luminous intensity values compared to Tests 0 and 1. The first version (see Figure 7a) achieves the minimum illuminance levels specified by the Polish standard (PN-EN 13201:2007). Test 3 (see Figure 7b) raises the minimum illuminance level for green areas to 2,5 lx, compared to Test 1, to reduce the disparity between the brightest and darkest areas. Similarly, the minimum illuminance for pathways is reduced to 3,5 lx in Test 4 (see Figure 7c).

The next set of tests investigates variants related to lamp height (see Figure 8). All other parameters remain the same as in Test 1 (see Figure 6 and Figure 8a). Test 5 shows the algorithm's results with higher lamps set at 15 m, while Test 6 presents the results with lower lamps set at 6 m.

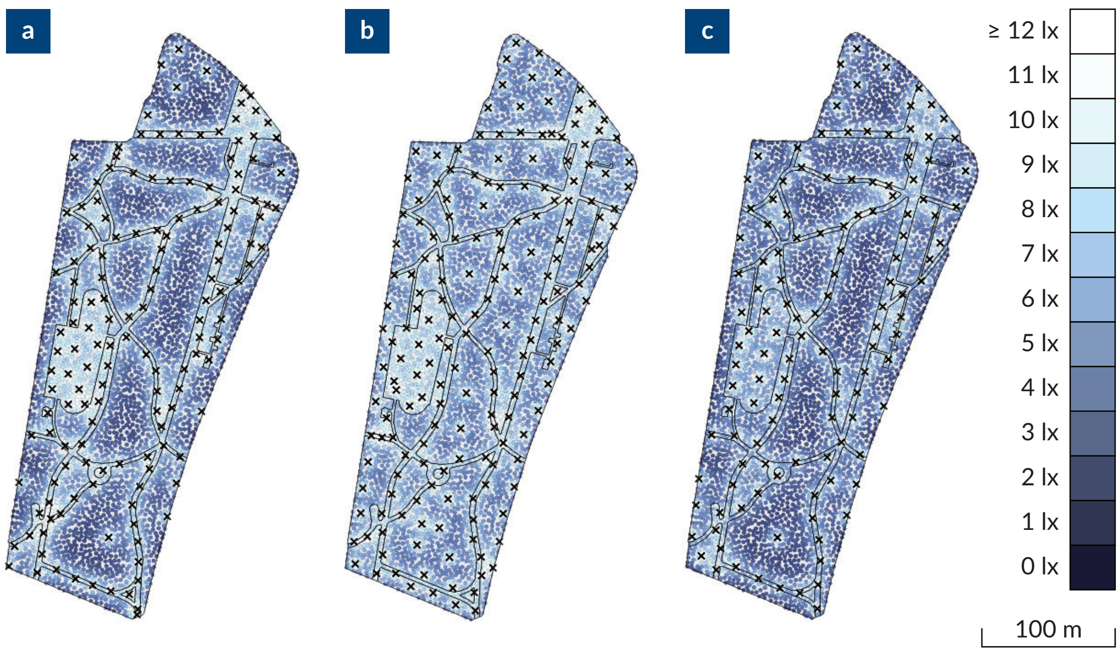

Figure 7. The results of the algorithm with reduced height and luminous intensity of lamps: a) Test 2, b) Test 3 (higher expected illuminance of lawn: 2,5 lx), c) Test 4 (lower expected illuminance of pathways: 3,5 lx).

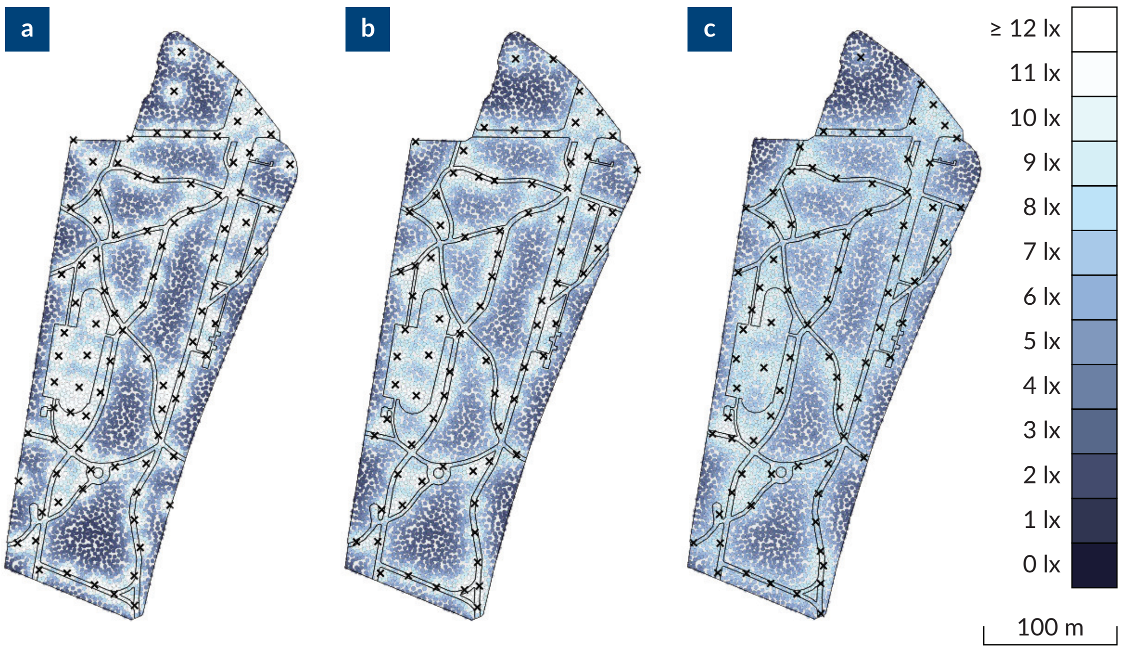

Figure 8. The algorithm results with the original luminosity of lamps but different heights: a) Test 5: 6 m, b) Test 1: 10 m, c) Test 6: 15 m.

5. Discussion

The results illustrate how the algorithm can influence the design process, effectively acting as an additional participant in the design workflow. By dynamically adjusting lamp positions and intensities based on input parameters, the algorithm introduces a level of automation that complements traditional design practices. Based on the given parameters, the algorithm creatively positions the lamps to achieve the desired minimum illuminance across various parameter variations. This unique capability ensures the desired illuminance levels and expedites the development of design variants, complete with visualizations of the resulting illuminance levels and the generation of quantitative data. These visualizations, such as false color maps, provide designers with actionable insights into light distribution patterns and areas requiring further refinement.

During the tests, it was observed that a key challenge in this design task is achieving the minimum illuminance levels while simultaneously minimizing one or more of the following factors: the number of lamps, the total lamp brightness, the average illuminance level, and the brightness of the brightest points, to reduce the contrast between dark and light areas. This balance is critical for meeting sustainability goals such as reducing light pollution, lowering energy consumption, and improving safety perception by avoiding overly bright or excessively dark zones. These factors are critical for various aspects of sustainability, including safety perception, light pollution, and energy consumption. Analysis of the tests' results indicates that reducing both the height and brightness of the lamps in Test 2 could lower overall luminous intensity and average illuminance while still meeting the required minimum illuminance levels (Figure 7a). Among the tests conducted, Test 6 achieved the lowest contrast of light—the difference between the darkest and brightest test point (Figure 8b).

This result demonstrates how parameter adjustments can optimize lighting configurations to minimize glare and improve uniformity while complying with regulatory standards. This data can be valuable for assessing solutions regarding light pollution, energy consumption, and overall well-being and safety. Ultimately, the algorithm-generated results can support critical design decisions, especially during the early stages of a project. Notably, with appropriately selected parameters, the algorithm produced results similar to the existing solution (see Figures 5 and 6). This similarity validates its potential as a decision-support tool for urban planners and lighting designers while highlighting its adaptability to real-world conditions. This outcome is particularly significant considering the nature of agent-based methods (Cudzik & Nessel, 2024) and the relatively simple set of rules governing agent behavior. This observation justifies the use of an agent-based approach for such tasks. The algorithm presented in this study uses expected illuminance data to generate designs. For example, such data might be represented by a grayscale bitmap (see Figure 9). In this experiment, the algorithm primarily operates on data regulated by legal standards. However, such a bitmap can also be created based on the designer's subjective decisions or to reflect public space users' expectations. This adaptability allows the incorporation of user feedback into lighting design processes through participatory approaches. Such flexibility aligns with contemporary urban planning trends emphasizing co-creation and stakeholder engagement (Jung & Kang, 2023). Such interaction could be facilitated through a web-based application combining location data with user feedback, such as opinions on whether an area is too dark or bright. For example, like how noise pollution data is used in tools like the Hush City App (Buongiorno Sottoriva et al., 2022), user-generated feedback on lighting conditions could create open-access maps reflecting localized illuminance expectations. Such a map can reflect co-creation expectations at a localized urban scale (Kashem & Gallo, 2023; Lorens & Zimnicka, 2023; Zidar et al., 2017). Leveraging the presented algorithm, these maps of illuminance expectations can be seamlessly converted into multiple design alternatives. Additionally, such a map would provide valuable geospatial data that could support long-term strategies in sustainable big-scale urban planning (Casiano Flores & Crompvoets, 2023),

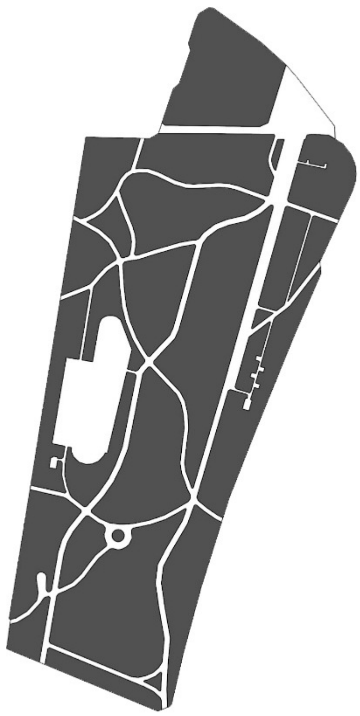

Figure 9. Grayscale bitmap representing expected minimum illuminance levels following the legal standards (white—5 lx, dark grey—1 lx).

potentially incorporating elements of artificial intelligence (AI) at some level (Tan, 2023). For instance, AI could analyze large datasets from user feedback to identify patterns or optimize lighting configurations across entire cities rather than individual parks.

While this concept is promising, challenges remain regarding engaging potential participants (Rodriguez Müller et al., 2024). Another critical issue is whether co-creation participants operate independently or are somehow guided by experts (Smith et al., 2024). Virtual Reality (VR) offers a promising solution to these challenges by providing immersive environments where users can evaluate lighting scenarios interactively. VR allows participants to experience proposed lighting designs in simulated environments before implementation, facilitating public engagement and expert validation (Krupiński, 2020; Kubiak, 2024). While illuminance evaluation may occur in real-world settings for existing spaces, VR enables assessments for spaces that do not yet exist. Utilizing VR for these evaluations can be engaging and informative for designers and users while ensuring expert guidance where necessary. Additionally, VR facilitates co-creation in designing spaces that do not yet exist, making it a valuable tool for revitalization projects and new design initiatives.

6. Conclusions

Algorithms represent a valuable tool in the early stages of lighting design, offering significant advantages such as the automatic creation of design variants that adhere to minimum illuminance criteria and the simulation, visualization, and numerical analysis of illuminance levels. These tools enable designers to explore creative solutions efficiently while ensuring compliance with technical standards, making them particularly useful in addressing complex urban lighting challenges.

These capabilities streamline the decision-making process and significantly enhance creative exploration, enabling designers to evaluate multiple scenarios efficiently. The algorithm's flexibility in accommodating various illuminance expectations makes it well-suited for participatory design processes, a key component in sustainable urban development. The algorithm bridges the gap between technical requirements and user preferences by incorporating user-defined illuminance levels into actionable lighting design solutions. This capability ensures that lighting designs are functional and aligned with community needs.

The algorithm's participatory potential is especially beneficial for urban revitalization projects, where existing public spaces require sensitive reimagining to enhance safety, functionality, and aesthetics while reducing environmental impact. In such contexts, the algorithm's ability to optimize lamp placement while minimizing factors like glare, energy consumption, and light pollution offers a practical solution for achieving balanced outcomes. Integrating VR into this process can further amplify the benefits, providing stakeholders with an immersive experience that supports dynamic generation, real-time visualization, and iterative participatory evaluation. VR enables users to experience proposed lighting designs interactively, fostering better communication between designers and end-users while allowing experts to guide the process effectively. This integration fosters better communication between designers and end-users and empowers communities to shape their environments actively.

Moreover, as introduced in this article, the illuminance expectations map offers significant value as a geospatial data resource. Such maps can be generated based on user feedback or legal standards and adapted for urban contexts. They provide planners with actionable insights into localized lighting needs while supporting long-term strategies for sustainable urban development. This map can be instrumental in guiding urban planners and designers towards more informed, responsive, and nature-friendly lighting solutions that balance the need for safety with the imperative to reduce light pollution. Additionally, these maps can serve as a foundation for integrating AI to analyze large datasets from user feedback or optimize lighting configurations across broader urban areas. By harnessing these advanced digital tools and methodologies, urban planning practices can evolve to become more adaptive, inclusive, and ecologically responsible, ultimately creating more intelligent, sustainable cities. The modular nature of the algorithm also allows for future extensions to incorporate additional parameters such as glare control metrics, uniformity ratios, color temperature adjustments, or energy efficiency considerations—further enhancing its applicability in professional lighting design contexts.

In conclusion, integrating algorithmic tools in public space lighting design advances the technical aspects of urban planning. It promotes a co-creative, user-centered approach that aligns with the broader goals of sustainable development. The synergy between advanced technologies like algorithms and VR, user engagement through participatory processes, and environmental stewardship represents a transformative direction for future urban design initiatives. This approach offers a pathway toward smarter and more sustainable cities that prioritize human well-being and environmental preservation by addressing functional requirements and ecological responsibilities.

Acknowledgments

The authors would like to thank the whole Outline AI team for their invaluable support.

Funding

This research was funded by Narodowe Centerum Badań i Rozwoju, grant number nr POIR.01.01.01–00-0900/21. Project name: Stworzenie technologii umożliwiającej za pomocą algorytmów na komputerową analizę nieruchomości i maksymalizację jej wykorzystania na cele Hotelowe. Project co-financed by the European Union from the European Regional Development Fund under the Działanie 1.1 Projekty B+R przedsiębiorstwa, Poddziałanie 1.1.1 Badania przemysłowe i prace rozwojowe realizowane przez przedsiębiorstwa, Pogram Operacyjny Inteligentny Rozwój. Publication of this article in open access was made possible through the institutional membership agreement between Gdańsk University of Technology—Faculty of Architecture and Cogitatio Press.

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

Upon request.

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Urban Planning
2025 • Volume 10 • Article 9234
https://doi.org/10.17645/up.9234

ARTICLE

Open Access Journal

A Socio-Spatial Extension of the Local Climate Zone Typology: Its Potential in Computational Planning Support Systems

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Submitted: 3 September 2024 **Accepted:** 25 February 2025 **Published:** 19 May 2025

Issue: This article is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

Computational planning support systems (CPSS) have been invaluable for the transparent and rational planning of climate-resilient cities as they help clarify and optimise the trade-offs between alternative choices. CPSS have shown great promise also as digital design boards for the co-creation of new solutions. However, both as a tool and a theoretical stance to spatial planning, CPSS have suffered from top-down representations of urban space. Bottom-up, collective, and subjective processes essential for sustainable and climate-resilient urbanism are often left unaccounted for. This article introduces one possible solution to this gap, namely structuring the information flows of CPSS according to the local climate zone framework, enriched with urban commons information. We illustrate our approach with data from the 29 largest Finnish municipalities. We combine OpenStreetMap and demographic information with local climate zone data to produce a socio-spatially extended local climate zone typology of Finnish urban forms. The results delineate a Nordic angle to sustainable spatial planning—green and sparse, somewhat compact and mixed, but not comprehensively so, built environments—allowing a juxtaposition with normative ideas about sustainable cities. We furthermore propose a co-design workflow that is based on our typology. The main practical applications of our work include vulnerability mapping and integrated impact assessment, multimodal communication of computer model output, and computationally-assisted co-design of built environments with a variety of stakeholders.

Keywords
co-design; computational planning support systems; local climate zones; neighbourhood typology; social sustainability; urban commons

1. Introduction: Computational Spatial Planning and Social Sustainability

While significant progress has been achieved in articulating sustainable spatial planning paradigms across such urban subsystems as land use and transport, economic development, and environmental management, their social sustainability is often unclearly articulated. Evidence has shown that popular paradigms merely offset impacts from one domain to another (Sera et al., 2019) and they often increase the disadvantage of vulnerable groups (Anguelovski et al., 2016; Blok, 2020; Shirazi & Keivani, 2019). In addition, what renders a given spatial planning paradigm sustainable is a contested topic (Echenique et al., 2012; Hautamäki et al., 2024; Votsis & Haavisto, 2019), which is itself part of a wider problem of vicious circles in Sustainable Development Goals (SDGs; Fanning et al., 2021; Pham-Truffert et al., 2020). In this article, we focus on one aspect of the ambiguities of sustainable spatial planning approaches, namely, their relevance and impact on everyday life. Computational planning support systems (CPSS) adopt a prospective mentality to impact assessment (Ness et al., 2007), assessing proposed solutions before the fact of their implementation across an array of urban subsystems (Wegener, 1994), offering significant assistance in evaluating the real-world implications of normative sustainable planning paradigms (Geertman et al., 2013; Pelzer et al., 2014). This is important, when one brings to mind the diverse multisectoral and long-lasting impacts that urban planning interventions can have on cities.

However, there is still much to be done with incorporating into CPSS a wider diversity of SDGs, especially relating social, ecological, and governance dimensions to spatial organisation (cf. Wegener, 1994; see also Hillier & Hanson, 2003). Climate resilience has experienced a paradigm shift toward community and societal aspects (Intergovernmental Panel on Climate Change, 2012), with inclusivity, fairness, and equality taking a central role (Together 2030, 2018). In the urban domain, critical work on urban commons highlights that resilience also implies that successful responses in and through urban space have a pronounced informal, non-institutionalized flavour, in which the coping capacity of each group is given space to develop (Ostrom, 2010; Petrescu et al., 2016; Sassen, 2017). Indeed, open-source, adaptive, tactical, and do-it-yourself urbanism (Bradley, 2015), along with numerous other citizen-centric models of urban planning, have been proliferating, as they empower inhabitants and facilitate the crucial role of bottom-up processes in cities. Thus, for CPSS the issue at stake is the realistic and relevant representations of the socio-spatial nature of the urban fabric. If CPSS are to avoid mistakes of the past (Lee, 1973, 1994), it is not enough that they represent the formal institutionalised functions of urban space (e.g., land uses or house prices) but also its social functions (e.g., what daily activities occur or could be encouraged in certain land uses). Bottom-up social-organisational aspects have to be incorporated in CPSS (McCann, 2017), continuing and extending the example of participatory mapping as a means of co-creating the built environment (Grêt-Regamey et al., 2021).

Our article aims to facilitate this fusion of formal representations of the built environment with more informal, non-institutionalized aspects of socio-spatial sustainability and resilience. We present an approach that is useful in two ways. First, we contribute to the need to standardise and communicate different kinds of built environments in a manner that also accounts for bottom-up social components. Second, we aid the redefinition of CPSS as tools that bridge planning science with planning practice, aiding co-creation and co-design throughout the stages of the planning process.

2. Theory and Methods

2.1. Urban Models and Local Climate Zones

Wegener (1994) systematised the urban processes that can be represented with computer models in the context of ex-ante urban policy assessments (Ness et al., 2007). These involve land use, housing, population, travel, networks, goods transport, employment, and workplaces, with specific models focusing on interactions between one or more of these sectors. According to Wegener (1994), these are embedded in the wider natural environment, which anticipated the proliferation of interest in environmental aspects that followed soon afterwards.

A recent development in connecting land use, housing, and population to the environment is local climate zones (LCZs) by Stewart and Oke (2012). LCZs are a built environment typology, based on the vertical height, density, textures, and materials of buildings, as well as the greenness and ground permeability of their neighbourhood. Human activity is accounted for but to a minor extent, featuring primarily the distinction between industrial and non-industrial phenotypes. Combinations of these characteristics produce 10 types (LCZ 01–10). Types 01–03 represent compact high-rise (01), mid-rise (02), or low-rise (03) built environments with minimum vegetation and stone, brick, tile, and concrete (02) or concrete, steel, stone, and glass (03) as the prevailing construction materials. Types 04–06 represent open high-rise (04), mid-rise (05), or low-rise (06) built environments with ample vegetation and perviousness in the neighbourhood, with concrete, steel, stone, and glass (05) or wood, brick, stone, tile, and concrete (06) as the prevailing construction materials. Type 07 represents lightweight low-rises with non-vegetated natural ground. Type 08 represents large low-rise buildings with minimum vegetation in the neighbourhood, whereas type 09 represents a sparse pattern of small buildings within an ample natural environment. Type 10 represents areas with "heavy industry" attributes (including residential patches) with minimal vegetation and metal, steel, and concrete as the prevailing construction materials.

LCZs link the material form and construction of a neighbourhood to its microclimate, because the 10 LCZ types respond differently to weather, yielding different diurnal energy balances and thermal profiles. LCZs thus attempt a standardised bridge between urban planning and climate resilience practice. Importantly, the typology provides a way to connect a neighbourhood's spatial layout to the weather and climate-related impacts implied by its material form and composition. If a neighbourhood is composed of one or more LCZ types, urban microclimate models can incorporate this information directly and translate it into micro-meteorological parameters, notably concerning thermal comfort, energy, drought and precipitation, and the urban heat island effect (Masson et al., 2020). LCZs are thus a way to deepen the ability of CPSS to assess how urban form and land cover connect to climate-related implications, notably exposure and vulnerability to climate change impacts, and a neighbourhood's energy balance, use, or demand profiles. However, the standardisation of LCZs has a main implication: one still ought to understand how LCZs look in specific cities if any ex-ante sustainability assessment is to be conducted in a manner that realistically connects to local conditions and processes.

2.2. Sociotope Mapping and Urban Commons

The present study aims to enrich the semantic diversity of LCZs, focusing on socio-spatial extensibility (cf. Yin et al., 2022). Within the necessity for urban planning to connect with citizen-centred bottom-up urbanism processes, and while the LCZ typology provides a link to urban climate, the link to human processes needs further elucidation. We operationalise our approach to fill this gap in CPSS by utilising "sociotope mapping." Ståhle (2006), drawing from Harvey (1989), distinguished between two major lenses through which architects and planners approach urban design and planning within a larger grid of spatial practices. On one hand, the built environment can be approached as a space of "domination and control," where top-down representations of urban space hold the major role through, e.g., land use, real estate property, or zoning maps and urban plans. However, as Ståhle (2006) also notes, this approach overlooks the dynamism that characterises the intentions, emotions, habits, and everyday practices attached to urban spaces as urban life unfolds. This highlights a second approach to the built environment, where "accessibility and distanciation" and "appropriation and use" are prominent lenses. Representations such as traffic analysis and space syntax are prominent in the former, whereas representations such as building typologies and sociotope maps are key for the latter. Within these bottom-up representations of urban space, Ståhle (2006), drawing from Lefebvre (1992, 1996), further distinguishes between lived (e.g., crime statistics on a map), perceived (e.g., sociotope map), and conceived (e.g., security zone map) space.

While LCZs reinterpret traditional land use representations of urban space into the domain of lived space, a further step can be achieved by extending them into the domain of perceived space through sociotope mapping. In this way, urban spaces are not represented exclusively in terms of their formal land use types—as typically done in CPSS—but can convey information about dimensions that are known to be essential for thriving and resilient cities (cf. Jacobs, 2011; see also Sassen, 2017): the social functions, everyday uses, and perceptions of urban space.

In this article, we adopt the idea of sociotope mapping and add to it elements of Ostrom's (2010) theory of the commons. Ostrom (2010) maintained that the sustainability of common goods—in our case, urban public spaces—is often being achieved throughout the world via bottom-up initiatives based on trust, reciprocity, and collective management by the community itself. Ostrom argued that this governance model is a successful alternative to market-based approaches to sustainability. The commons have proliferated in theory and practice, with a literature corpus of tremendous size that moves beyond the scope of our article. Nowadays, the notion has been extended to include the so-called "new commons," that is, common goods beyond the traditional domain of natural resources. A prominent category of new commons is the urban commons. Like sociotopes as a representational approach to perceived spaces, urban commons emphasise socio-spatial processes, with scholarship focusing, among others, on the informal and often non-institutionalized uses of public and private common spaces in cities. This often reveals the inconsistency between the originally intended uses of the built environment and the everyday ones by its users. Especially in moments of crisis, seeing the built environment through the lens of urban commons shows the potential that the reinterpretation and reappropriation of urban spaces have—outside prescribed or even legal uses—for giving vital room for local solutions to societal resilience, particularly by vulnerable citizens (Adianto et al., 2021). It is crucial to represent this bottom-up potential in CPSS.

Empirically, Ståhle's (2006) original sociotope mapping utilised observational fieldwork, which offered a depth of perceptual information for a well-defined urban area. In this article, we are proposing an alternative approach that can operationalise sociotope mapping in metropolitan, regional, or multi-city settings, where limited resources cannot allow large-scale in-depth fieldwork. Drawing from Ostrom (2010), Agyeman et al. (2013), and Boydell and Searle (2014), we adopt three dimensions to understand the potential of a neighbourhood for urban commoning: ownership, access, and rivalry surrounding an urban common. We especially draw from the study of Boydell and Searle (2014), who focused on the intersection between urban commons, property rights, and their implications for the citizens' right to the city. Ownership is operationalised as public or private urban commons, grounded on the fact that urban commoning does not happen only in public spaces such as a public square, but also in "public" areas of nominally private spaces such as the public area of a shopping mall. Access is operationalised as exclusive or nonexclusive in order to reflect the fact that access to either public or private common spaces may or may not be normally restricted by exercising (or not) the rights that follow from ownership of the space. Rivalry is operationalised via the scarcity of an urban commons within the boundaries of a neighbourhood, as the number of the neighbourhood's dwellers per the number of instances of the urban common resource. For comparability of neighbourhoods of various sizes across Finland, we normalised scarcity to 0–100%, with higher numbers denoting higher rivalry potential. While this operationalisation hinges on the assumption that most of the use of an urban commons occurs in its vicinity, which is not always true due to urban mobility and the purely administrative nature of neighbourhood boundaries, it assists in capturing a foundational component of urban commons, namely tensions and contestations surrounding their use. Putting these dimensions together, we develop a commons-based representation of urban space as public or private versus exclusive or nonexclusive, which leads to four categories (private exclusive, private nonexclusive, public exclusive, and public nonexclusive), which are further characterised in terms of their rivalry potential due to scarcity. These categories aim to operationalise foundational notions of urban commons as discussed by Ostrom (2010), while also relating to key notions of the theory of public goods (Gruber, 2022).

2.3. Implementation in Finnish Cities

The LCZ classification of Finland was retrieved by accessing the work of Demuzere et al. (2019). This is a raster representation that applied machine learning methods on multisource land use data to develop a 100-by-100-metre categorisation of continental Europe into the various LCZ types. Missing urban areas on near-coast islands of Finnish cities were filled-in from the original ECOCLIMAP dataset of Faroux et al. (2013). We produced a dataset of LCZ types for the largest Finnish cities, namely the greater Helsinki metropolitan area (municipalities of Espoo, Helsinki, Kauniainen, Kotka-Kouvola, Riihimäki, Sipoo, Vantaa, and Vihti), and the cities of Hämeenlinna, Joensuu, Kuopio, Lahti, Oulu, Pori, Rovaniemi, Salo, Tampere, Turku, and Vaasa-Seinäjoki. In order to produce a demographic characterisation of each LCZ type in Finnish cities, namely the gender and number of residents typically found in each LCZ type, we appended to the LZC pixels information found in the 250-by-250-metre gridded demographic dataset, produced by Statistics Finland (2020). In order to harmonise the scale inconsistency between the LCZs and demographic data, we used a spatially weighted version of the spatial overlay analysis, where the population and gender numbers in each 250-metre demographic pixel were distributed into the overlapping 100-metre LCZ pixels in proportion to the degree of aerial overlap between each demographic and each LCZ polygon.

Implementation of the urban commons approach discussed in Section 2.2 was achieved by using data from OpenStreetMap (OSM). OSM is a free editable world map that is generated by a global community of mappers. OSM data are used in various urban applications to map streets, buildings, green spaces, amenities, and activities (see Boeing et al., 2022). While OSM data may have gaps, it is overall the most extensive openly available data set on urban features. In Finland, OSM data are used, e.g., in regional journey planning applications increasing the motivation of the local mappers to keep the map contents up to date. We retrieved point-of-interest data related to sports and leisure facilities, historic locations, shops, and various other amenities (see the full list of features in the Supplementary Material, Workbook S2). We used a custom Python algorithm based on the OSMnx Python package (Boeing, 2017) to access the data via the Overpass Application Programming Interface. The algorithm and the retrieved OSM data from Finnish cities are available online at Heikinheimo (2025). In total, we retrieved data points under approximately 100 tags from OSM. These were categorised according to the access and ownership dimensions (see Section 2.2), while at the same time using population data to compute the scarcity dimension.

3. Results

3.1. The LCZ Composition of Finnish Cities

Figure 1 provides a visual summary of the Finnish LCZ forms based on OSM data, together with the relative frequency and population density of each type. The Supplementary Material (Table S1) provides a more detailed summary of the average LCZ composition in Finnish cities and its variations from one city to another.

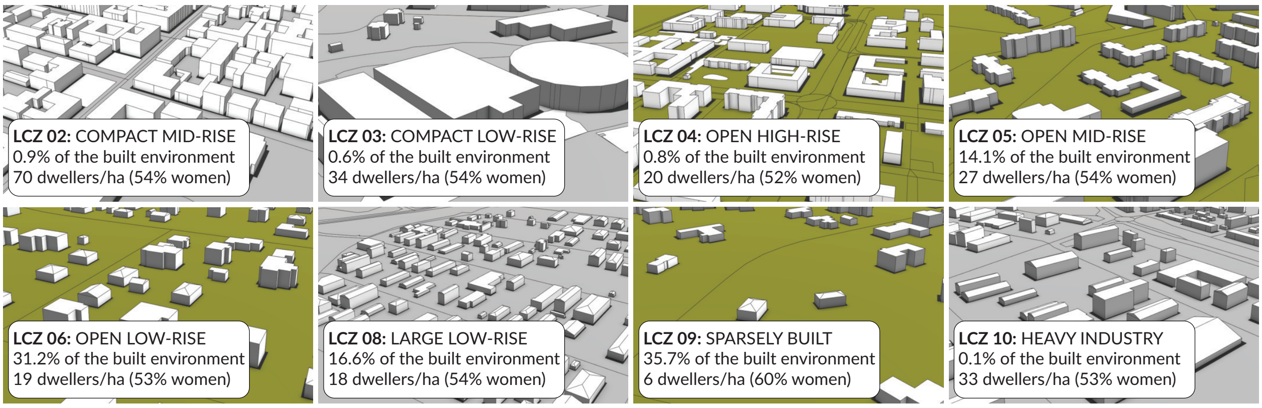


Figure 1. Visual summaries of the Finnish LCZs.

Compact high-rise neighbourhoods are not present in Finland; the densest LCZ types that are present in our sample are compact mid-rise and compact low-rise with a rather low share of the total urban area, about 1% each. Green neighbourhood morphologies are the dominant types; open low-rise neighbourhoods dominate the cities with 31.2% of the total areas, followed by open mid-rise (14.1%) and open high-rise (0.8%). The most extensive LCZ type in our sample of Finnish cities is sparsely built neighbourhoods, representing 35.7% of the total urban area. Large low-rises represent 16.6%, whereas there are traces of areas of "heavy industry" character in a few cities of the sample. These averages indicate the prevailing neighbourhood composition of the largest Finnish cities. Under this light, Finnish cities are dominated—physically—by green sparsely built and open low-rise neighbourhoods (67% in total), with a notable presence of green large low-rises and open mid-rises (31%). These relatively sparse, low, and green neighbourhoods collectively represent 98% of the total area of our sample of Finnish cities. Although there is variation from city to city, this pattern seems to hold as the general rule. We link this to sustainable spatial planning paradigms in Section 4.

3.2. Socio-Spatial Characteristics of Finnish LCZs

Table 1 (country-scale descriptive statistics), Table 2 (cross-city comparison), and Figure 2 (overview at varying spatial resolutions) provide a summary of the OSM data as interpreted from the urban commons standpoint (cf. Section 2.2 and Section 2.3). The two most populous urban commons types in terms of ownership and access, in a typical postcode of a Finnish city, are public nonexclusive (41 commons on average) and private nonexclusive (38 commons on average), therefore indicating a pervasiveness of commons that are accessible regardless of their ownership status. Exclusive commons follow, with private exclusive types being 26 on average and public exclusive just 8 on average in a typical urban postcode. In terms of scarcity, the prevailing pattern is 134 permanent dwellers per commons in a typical postcode, which translates to a rather low rivalry potential of 1.6%. These averages, if taken as a first hint at the neighbourhood scale, indicate an abundance of accessible commons with low rivalry potential, which could be interpreted as neighbourhoods with a certain fluidity in terms of the functions of common spaces, although the ground reality remains uncertain, given the present data. When neighbourhood commons are minimal, these appear to come in the form of traditional private goods (cf. Gruber, 2022). However, there is notable variability from one postcode to another across the analysed cities, with a notable range between minimum and maximum numbers. Figure 2 indicates that this geographical variability does not always relate to the size of the city but has to do also with the location of the neighbourhood within a city, with central and presumably denser areas exhibiting higher numbers of neighbourhood commons. At the same time, Table 2 does indicate a slight decline in the provision of commons as one moves from dense and populous (Helsinki and Turku) to sparse and less populated (Rovaniemi and Kauniainen) municipalities. This appears to be the case with both the absolute numbers of commons and their amounts per hectare in each access and ownership category. As expected, rivalry is higher in the larger and denser cities (cf. Helsinki and Turku versus Rovaniemi), but Kauniainen shows that rivalry in a sparse and administratively small place can be nearly as high as in large cities, if the place is part of a metropolitan system (Kauniainen is a constituent of the Greater Helsinki area).

Table 1. Distribution of urban commons types at the national scale.

Urban commons aspect	Total	Postcode mean	Postcode maximum	Postcode minimum
Private exclusive	22,377	26	1,107	0
Private nonexclusive	33,439	38	357	0
Public exclusive	7,212	8	190	0
Public nonexclusive	35,957	41	538	0
Rivalry (mean dwellers per commons)	—	134	8,165	0

Table 2. Comparison between the densest (Helsinki and Turku) and sparsest (Rovaniemi and Kauniainen) cities.

	Helsinki		Turku		Rovaniemi		Kauniainen	
Urban commons aspect	Total	Per hectare (ha)	Total	Per ha	Total	Per ha	Total	Per ha
Private exclusive	6,074	1	1,745	0.9	227	0.7	25	0.1
Private nonexclusive	6,001	1	1,675	0.9	215	0.6	134	0.3
Public exclusive	817	0.1	228	0.4	55	0.2	14	0.03
Public nonexclusive	7,472	1.2	1,348	0.7	144	0.4	75	0.2
Rivalry (mean dwellers per commons)	29	—	24	—	11	—	19	—
Demographic diversity								
Dwellers	534,092	—	139,287	—	28,825	—	10,124	—
% women	52.8	—	52.9	—	52.7	—	51.9	—

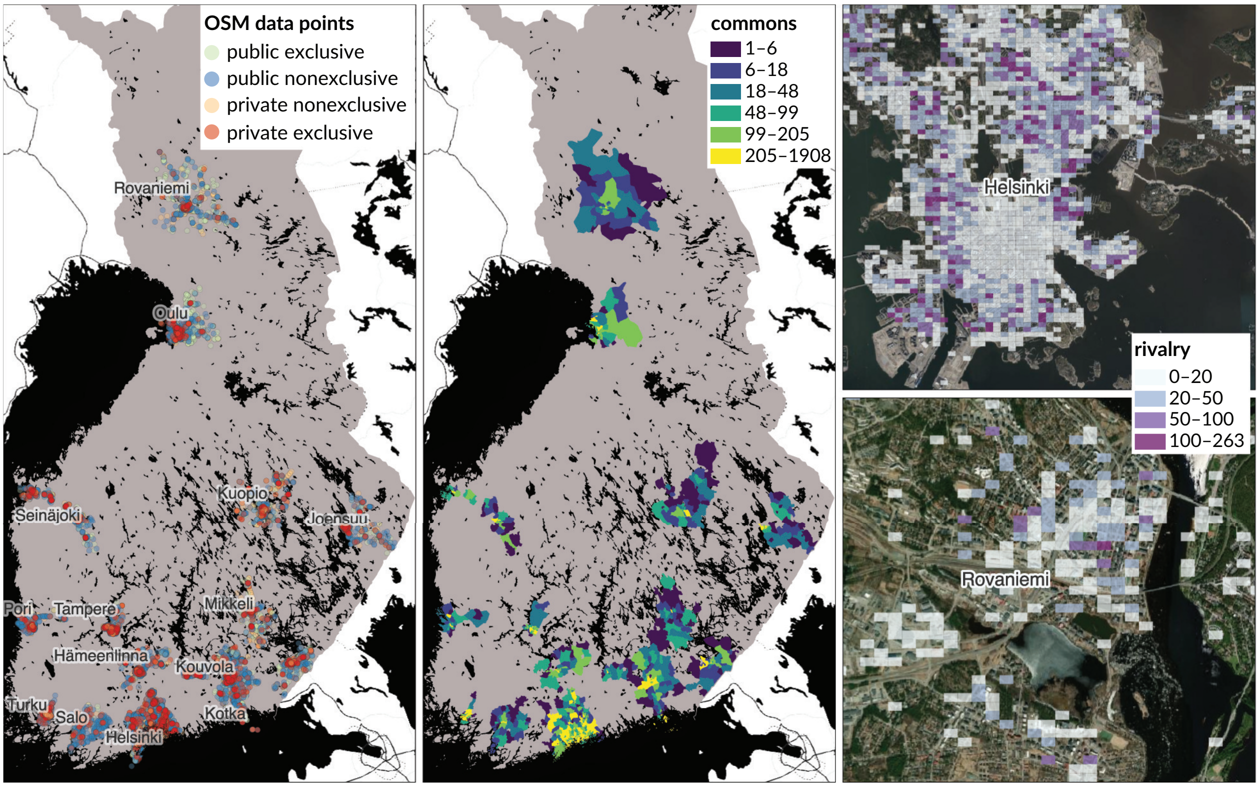


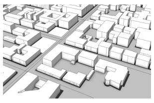
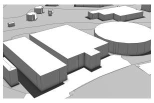
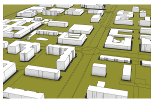
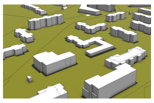
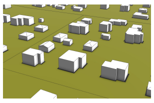
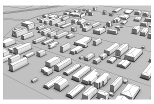
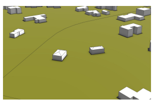
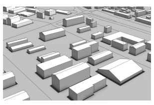
Figure 2. OSM data points categorised by ownership-access (left), total commons per postcode (centre), and rivalry (dwellers per commons) for the 1 ha LCZ pixels in Helsinki (right top) and Rovaniemi (right bottom). Note: The background maps is Stamen for the images in the left and central rows, and Bing Maps for those in the right row.

3.3. The Extended LCZs Typology for Finnish Cities

A more detailed view of urban socio-spatial patterns can be produced by associating the urban commons attributes of Section 3.2 with the LCZ patterns of Section 3.1. We further add basic demographic information for each LCZ in order to demonstrate the number of inhabitants in a typical LCZ type and the gender balance.

Each LCZ type is standardised to a one-hectare patch (100 by 100 metres). This is important, because—getting back to our introductory discussion—model output for a specific urban patch can be in this manner associated with urban fabrics found in reality, at least in terms of key social and physical parameters related to resilience. Table 3 provides an overview of the extended LCZ typology for Finnish cities, based on our sample of the 29 largest municipalities in Finland.

Table 3. A typology of Finnish neighbourhoods, per LCZ, urban commons, and demographics.

One-hectare LCZ patch	Built-up morphology		Urban commons and demographics		
	3D shape [(a)]	Ecology [(a)]	Urban commons types [(b)]	Urban commons rivalry [(c)]	Demographics [(d)]
02 Compact mid-rise 	Tightly packed buildings 3–9 floors	Few/no trees and little/no green space	0.55 0.23 0.02 0.19	3 8 100 10	70 (54%)
03 Compact low-rise 	Tightly packed buildings 1–3 floors	Few/no trees and little/no green space	0.35 0.29 0.04 0.31	2 3 24 3	34 (54%)
04 Open high-rise 	Openly arranged buildings of 10 + floors	Abundance of trees and pervious cover (low plants)	0.14 0.40 0.04 0.41	4 1 14 1	20 (52%)
05 Open mid-rise 	Openly arranged buildings of 3–9 floors	Abundance of trees and pervious cover (low plants)	0.20 0.40 0.06 0.34	4 2 13 2	27 (54%)
06 Open low-rise 	Openly arranged buildings of 1–3 floors	Abundance of trees and pervious cover (low plants)	0.12 0.41 0.08 0.37	4 1 6 1	19 (53%)
08 Large low-rise 	Large and openly arranged buildings of 1–3 floors	Few/no trees and land mostly paved	0.33 0.34 0.04 0.24	1 1 13 2	18 (54%)
09 Sparsely built 	Sparse arrangement of small- or mid-sized buildings	Natural setting and abundance of pervious cover	0.11 0.34 0.08 0.48	1 0 2 0	6 (60%)
10 Heavy industry 	Low- or mid-rise industrial structures	Few/no trees and land mostly paved or hard-packed	0.63 0.18 0.02 0.18	1 5 47 5	33 (53%)

Notes: (a) Source: Stewart and Oke (2012) and Ching et al. (2018); (b) number per hectare for: private exclusive, private nonexclusive, public exclusive, and public nonexclusive; (c) in-sample min-max normalised index with 0% minimum and 100% maximum rivalry potential; (d) total number of inhabitants per hectare (with % of women in parenthesis).

Altogether, we can maintain that Finnish cities seem to typically focus on sparse urban forms. It can be seen from Table 3 and Figure 1 that green sparsely built and open low-rise neighbourhoods dominate, which tend to offer to their dwellers urban commons of public and private nonexclusive character, with rather low rivalry potential as the number of commons tends to exceed both the number of buildings and dwellers in a neighbourhood. A few cities tend to have denser centres, and the typology shows that these offer high numbers of neighbourhood commons. Finnish cities appear to present a planning approach of mixing rural and urban land uses, with relatively good access to relatively abundant urban commons. In such a case, one could anticipate different risk and resilience patterns, depending on what type of LCZs are implemented. For instance, preferring an LCZ 02 type of residential development will mean different exposure (e.g., number of inhabitants) and vulnerability (e.g., urban commons processes) as opposed to following an LCZ 04 type.

There are no compact high-rise areas (LCZ 01) in Finnish cities. The compact mid-rise type (LCZ 02) is observed, with buildings of a maximum of nine floors theoretically, but fewer in practice. The largest continuous LCZ 02 area is located in Helsinki's city centre. From there, the city spreads sparsely outwards to the rest of the Finnish capital region. In most of the cities, LCZ 02 covers less than 2% of the built area (cf. Supplementary Material, Table S1), with the exception of Helsinki, Turku, and Tampere, which can be seen in the light of Münter and Volgmann's (2021) note that today the division between rural and urban tends to be blurry due to mixed land uses. Regions may appear polycentric with one dominating centre with global visibility such as Espoo, Vantaa, and Helsinki, with Helsinki being the most known and dominating centre. All cities except one in our sample contain LCZ 02 areas, usually near the city centre, and normally not large or contiguous. Open mid-rise (LCZ 05) neighbourhoods normally dominate near the city centres, which are typically characterised as compact mid-rise style and openly arranged. When moving toward the Finnish north and east, cities tend to be less dense with fewer LCZ 02 neighbourhoods, presumably due to lower population numbers compared to Helsinki and the south.

Alongside mid-rise neighbourhoods, Finnish cities have typically exceptionally low numbers of (under three floors) compact low-rises (LCZ 03), and a higher number of (more than 10 floors) open high-rises (LCZ 04). Both still cover less than 3% of the built area in every city (cf. Supplementary Material, Table S1). Helsinki is an exception, dominated by compact mid-rise (LCZ 02) and open mid-rise (LCZ 05) resulting in a comparatively more even skyline. Other cities have on average more LCZ 04 (0.81%) than LCZ 02 (0.74%), yet LCZ 05 is the most dominating neighbourhood type (13.47%) from the high and compact LCZ types. Thus, Finnish cities typically appear to have low-density neighbourhoods but also sparsely built high-rise neighbourhoods.

Heavy industry (LCZ 10) and large low-rise (LCZ 08) contain most of the commercial infrastructure. These are low-rise areas with buildings of a maximum of three floors, where the land is mostly paved and with minimal amounts of trees. In our sample, heavy industry (LCZ 10) is rarely contiguous and concentrated at one location of the city such that it would stand out as its own separate area. Only nine cities (out of the 29) had LCZ 10 pixels and they covered only 0.05% of our research area (Supplementary Material, Table S1), normally close to water and city centres. Only coastal municipalities exhibit LCZ 10. Despite its name, however, in Finland LCZ 10 does not exclusively contain heavy industry, but rather residential neighbourhoods with an "industrial feel" by building height and style, and amount of greenery. LCZ 08 is significantly more common than LCZ 10, as all cities in our sample contain between 5.35% and 28.86% of it. This LCZ contains airports, port areas, and commercial units and thus it is very common just outside the city centre.

The suburban landscape is dominated, in addition to large low-rise (LCZ 08), also by open low-rise (LCZ 06), and sparsely built (LCZ 09) neighbourhoods, which implies neighbourhoods with a maximum of three floors. LCZ 09 is the most common type in our sample (Supplementary Material, Table S1). In smaller municipalities, sparsely built neighbourhoods are the only ones found outside the city and its immediate area of influence, and even more so in the Finnish north and east. This LCZ type is evenly spread throughout these municipalities; for instance, in Rovaniemi and Joensuu, it covers more than 80% of the built area. On the other hand, Helsinki in the Finnish south exhibits less than 10% of sparsely built neighbourhoods, although open low-rise (LCZ 06) is the second most common type (27.19%) after open mid-rise (30.99%) (LCZ 05).

4. Discussion

We attempt now a shift toward a broader discussion on knowledge co-creation about sustainable and resilient cities and their co-design. On one hand, the socio-spatial extension of the LCZ typology provides a possible—though certainly not the only one—way to a dialogue between the global academic literature on sustainable cities and the empirical choices of Finnish planning practitioners. On the other hand, the typology helps to systematise and communicate the recommendations and role of CPSS in the co-design of future cities. We discuss these meta-concerns in Section 4.1 and Section 4.2 respectively, while also summarising the latter in the concluding section.

4.1. Finland's LCZ Patterns in the Context of Sustainable Spatial Planning Paradigms

While the LCZ typology does not exhaust the array of elements that researchers have been identifying as factors of urban sustainability, a socio-spatial extension of the typology adds to our capacity to treat a number of these concerns from a more integrative perspective. Through sustainable planning paradigms, we could argue that reading a city through a socio-spatial LCZ typology helps us understand the responses of Finnish urban planning practice to academic deliberations about the physical and social properties of sustainable cities. This juxtaposition between practice and theory has its merits, considering the long-held image of Nordic cities as leaders in sustainability—we could further argue that a dialogue between global sustainable cities literature and empirical choices in Finnish cities offers an additional angle to the co-creation of knowledge about spatial sustainability and resilience.

Academically, discussion about the physical characteristics of sustainable cities revolves around: (a) urban form and growth (Banister, 2008; Boschmann & Kwan, 2008; Burton, 2000; Burton et al., 1996; Dixon & Eames, 2014; Jabareen, 2006; Münter & Volgmann, 2021; Newman & Kenworthy, 1999; Pandit et al., 2017; Pendall et al., 2002; Taniguchi & Ikeda, 2005; Zhang et al., 2011), (b) land use (Echenique et al., 2012; Hautamäki et al., 2024; Houghton & Castillo-Salgado, 2019; Kühn, 2003; Masnavi, 2000; Medved et al., 2020; Santamouris, 2013; Saranko et al., 2020; Sera et al., 2019; Tang et al., 2007; Votsis, 2017), and (c) transportation (Banister, 2008; Boschmann & Kwan, 2008; Krausse & Mardaljevic, 2005; Masnavi, 2000; Proske & Zdarilova, 2020; Williams, 2017). Researchers furthermore focus on the features of houses (Coutts et al., 2013; Estrada et al., 2017; Leal Filho et al., 2018; Luederitz et al., 2013; Medved et al., 2020; Sera et al., 2019; Yang et al., 2015), energy systems (e.g., Dixon & Eames, 2014; Jabareen, 2006; Kazimee, 2002), and environmental quality (e.g., Anguelovski et al., 2014, 2016; Kazimee, 2002; Luederitz et al., 2013; Uittenbroek et al., 2013). Community-related parameters are also discussed in the literature, more specifically the balance and mix between public and private space (Agyeman et al., 2013; Boydell & Searle, 2014; Kazimee, 2002), sociocultural diversity (Blok, 2020; Estrada et al., 2017; Jabareen, 2006; Kazimee, 2002; Pandit et al., 2017), education and inclusiveness (Anguelovski et al., 2016; Boschmann & Kwan, 2008; Dixon & Eames, 2014; Jabareen, 2006; Lanfranchi et al., 2018; Medved et al., 2020; Pandit et al., 2017; Puustinen, 2006; Sera et al., 2019), local economic development (Bagheri & Hjorth, 2007; Kazimee, 2002; Luederitz et al., 2013; Zhang et al., 2011), technology (Anguelovski et al., 2014; Caparros-Midwood et al., 2015; Hippi et al., 2020), and health and well-being (Banister, 2008; Dixon & Eames, 2014; Echenique et al., 2012; Houghton & Castillo-Salgado, 2019; Pugh et al., 2012; Rupp et al., 2015; Sera et al., 2019; Sörensen et al., 2016).

The empirical reality of Finnish spatial forms, when seen through the LCZ lens, appears to emphasize some of these elements while discouraging others, offering a distinctive Nordic interpretation of sustainable spatial planning: green and sparse, somewhat compact, and mixed but not comprehensively so built environments. In particular, the predominant production of residential spatial patterns in Finnish cities appears to favour open, mid/low-rise, and green forms, with compactness appearing only in a few large cities (Figure 1), which provides a Nordic view to the question of urban form occupying the literature. Furthermore, green and low-intensity LCZs are prevalent, which appears to be the preferred implementation of mixed land use and a strategy for connecting or separating features between city elements. On one hand, this links to additional literature about the benefits of urban vegetation (Hautamäki et al., 2024; Houghton & Castillo-Salgado, 2019; Houghton & Pugh et. al., 2012). On the other hand, there is limited implementation of the idea that mixed land use moves beyond mixing the rural with the urban, as it locates jobs, shops, and leisure facilities near each other (Jabareen, 2006). This is mostly found in compact LCZs with a variety of urban commons present (Table 2), whereas there is some presence of commercial and light industrial activities in large low-rise and residential-industrial LCZs. Interestingly, there are no comprehensively mixed land use LCZs—in Finland, it appears that mixing the rural into the urban is implemented separately from mixing diverse activities into the built environment.

4.2. Planning Paradigms and Computational Support for Co-Designing Sustainable Cities

Although participation has been central in imagining and negotiating sustainable pathways, co-design is paramount as it adds the experiential, tangible, and “artefactual” dimensions of sustainable urban futures (Candy & Dunagan, 2017; Hovorka & Peter, 2021). Design for sustainability is further considered to be a task of systemic embeddedness, that is integrating the object of design into the wider socio-technical system (Ceschin & Gaziulusoy, 2016). This invites a discussion about CPSS as co-design tools, that is, how are we to position a socio-spatial LCZ typology, as part of CPSS, in the co-design of urban futures? We develop this discussion by positioning co-design in the interplay between major urban planning paradigms (Taylor, 1998). We argue that a socio-spatial extension of the LCZ typology seeks to fulfil key concerns of co-design as a communicative planning paradigm, but at the same time, it reconnects this paradigm to long-standing physicalist and rationalist approaches, therefore facilitating the systems integration character of today’s design for sustainability.

In particular, physical planning was envisioned as a top-down design-driven planning of the physical environment as opposed to social, economic, or political planning (Taylor, 1998, p. 13). As hinted in Section 1 and Section 2, the strong point of this paradigm is a systemic approach to designing sustainable built environments. A drawback of this approach is rigidness when it comes to understanding how various urban processes come together to form a functioning unity. Rationalist planning responded to this drawback by informing decisions with scientific knowledge about a city's processes. Rationalist planning reaches specific pre-determined goals (Taylor, 1998), based on research and scientific knowledge. The "rational" essentially amounts to instrumental rationality (mean-to-end) and reflects a search for the most effective and efficient solutions for pre-set goals, an approach that drew significantly from decision theory which, at that point, was outside the planning discipline. Another criticism of physical planning points to the lack of in-depth discussion of social and political processes, as well as its blindness to the underlying social reasons for urban change, which are fundamental in understanding not only the nature of social sustainability but also social aspects such as people's preparedness to react and accept changes towards sustainability. The communicative paradigm gives voice to the inhabitants of a city. This paradigm refers to planning practices based on shared interactive activities (Puustinen, 2006) and in practice, it is understood as participatory planning and co-design. In this paradigm, everyone affected by a plan should have the possibility to participate in decision-making (Healey, 2020; Taylor, 1998, p. 123) and understand the process and criteria. The planner's judgment is rarely free of preference and value and so public participation ensures that the interests of different groups of urban dwellers are considered in planning decisions.

The point is that co-design fulfils elements of all three major planning paradigms, although it is often erroneously seen as a communicative approach only. Historical shifts in planning paradigms indicate that overemphasising one aspect of urban planning has never been sufficient for achieving a well-faring sustainable urban society. From our perspective, a balanced combination of the elements of all three approaches is needed: (a) the physical paradigm provides the necessary safeguards of a well-designed functional built environment, (b) the rationalist approach brings decision theory and mean-to-end rationality into planning, (c) whereas the communicative paradigm accounts for the dwellers' interests.

So, the challenge to which this article contributes is to find a way to amend computer models of cities with bottom-up information, so that sound co-design—and not mere participation or loose co-creation—is achieved. Our choice was to expand the connection between the built environment and microclimate to include social indicators, overlaying an element of the communicative approach on a pre-existing model of physicalist-rationalist approaches. We implemented this by overlaying urban commons parameters on an existing LCZ typology in the major Finnish cities, testing how the addition of a communicative approach layer would look in practice in an empirical sample of cities. This invites further research and discussion into the advantages and limitations of incorporating information that is important for the communicative approach while acknowledging the capacity of computer urban models to work with the physical properties and scientific facts of built environments. We have also put forth a working hypothesis—which, too, invites further discussion—that urban commons information is one of the most promising instruments for reflecting elements of the communicative approach into other planning paradigms that are important but nevertheless suffer from the lack of bottom-up feedback. Some of the features that speak in favour of urban commons as such an instrument are:

- Urban commons depart from "dominance and control" (cf. Ståhle, 2006; Harvey, 1989) representations of urban space, offering instead an insight into representations of perceived and lived spaces (cf. Ståhle, 2006; Lefebvre, 1996); everyday uses of urban spaces naturally developing from the life flow of the dwellers.
- By doing so, urban commons information adds elements to computational co-design that are part of the climate resilience of the dwellers of urban spaces, rather than of only material urban spaces.

- Urban commons data provide relevant guidance about the more social aims of the UN Agenda 2030, particularly SDG 5 “gender equality,” SDG 10 “reduced inequalities,” and SDG 16 “peace, justice, and strong institutions.”

4.3. Limitations and Future Directions

The proposed new parameters introduce bottom-up informal activities of social groups. This is due to the feature of the corresponding source data by OSM, which maps a variety of citizen-reported social uses of buildings and urban spaces. However, urban commons are more than spatial activity and deal with several “invisible” cognitive and institutional processes, which we expect to have spatial expression, as Hillier and Hanson (2003) theorised. It is therefore fair to note that such data should be seen more precisely as indications of the presence or the potential for those social processes, rather than ultimate confirmation of them. Future work on this aspect can be the inclusion of additional parameters as a way to represent a broader cluster of such self-reported social activities, which can serve triangulation and interpretation robustness purposes. One example of such a parameter could be sub-daily mobility data so that estimating rivalry potential does not rest on static population statistics, but on the locations of citizens during their daily flow of activities. Another example could be sentiment data, which would illuminate part of the intentionality of citizens towards their spaces and therefore provide interpretative capacity for the types and distribution of urban commons that we observe in OSM data. A third example is to produce sub-types of urban commons data within the general private/public and exclusive/nonexclusive classification framework. This would allow a better understanding of the nature of social processes surrounding each point of interest. For instance, a community garden revolves around different socioecological processes than a library which is nowadays more related to digital commons and the knowledge commons.

Collecting such information by fieldwork (such as surveys, interviews, or notes) can further expand or replace the capacity of the OSM data to reach the underlying social processes. Such fieldwork is ideal for one location, but utilising community information found in OSM is more feasible for large-scale studies. Future research should address limitations surrounding the use of OSM data. Firstly, OSM information concerning the social uses of urban space is not a complete replacement for interviews or field observations. Information derived from OSM data should be rather seen as a proxy for fieldwork data that, although not providing the same depth of meaning, can produce information for a large number of locations in an automated manner. Secondly, although we use in this case OSM’s crowdsourced nature as an advantage in order to survey the social uses of urban space, researchers should be also aware of the inherent biases, pertaining for instance to the demographic groups that have volunteered geoinformation, as well as biased geographical representation. Although the literature indicates that OSM data are as a rule of equal quality to official geospatial information (Haklay, 2010), we expect that such biases are more pronounced in those parts of OSM that pertain to the meaning of urban space as opposed to its description as mere infrastructure. Lastly, the discussion throughout this article has included both sustainable spatial planning and climate-resilient cities as scopes, which may appear too broad. Although the LCZ typology is about climate resilience, this goal should be approached as a subset of the wider problem of spatial sustainability, from a socio-spatial perspective and also from a more theoretical sustainable spatial planning angle.

Lastly, although 8 out of the 10 LCZ types are represented in our sample, the majority of LCZs are low-intensity ones. This implies that the correlations between the socio-spatial parameters and LCZ types are less robust for the high-intensity types. Future research should address this issue by including a more balanced sample of LCZ types, which in the Nordic-Baltic context can be found, for instance, in Sweden, Denmark, and Estonia.

5. Conclusion: A Computational Co-Design Workflow

This article proposes a data-driven socio-spatial extension of the LCZ typology. Our approach relies on OSM data to retrieve urban commons information that, together with demographics, adds social content to the climate information of the original LCZ types. We can approach the extended typology as communicating what typical climate and social characteristics one expects to find in 10 built environment forms that we observe in the real world. We demonstrated this approach with data from the 29 largest Finnish municipalities at the 100-by-100-metre spatial resolution. We subsequently shifted the discussion to wider theoretical concerns. We posited that the typology is one way to detect a dialogue between the global academic literature on sustainable cities and the empirical choices of Finnish planning practitioners and positioned our work in the mutual interdependencies between three key planning paradigms.

Our underlying assumption is that CPSS ought to incorporate—or at least communicate—more of the bottom-up informal processes that contribute to societal resilience. This expansion in scope rests on their physicalist-rationalist merits but aligns them better with today's communicative turn in planning. By doing so, CPSS can provide a valuable co-design tool for urban sustainability. Our typology proposes to organise spatial sustainability alternatives by reference to real-world built environment types and what we know about their social and physical fabric. These design alternatives do need to be informed by scientific models of urban mechanisms so they can assess what aspects of the proposed designs are sustainable and what may be mere wishful thinking. But one must also be able to communicate scenarios that represent the lived environment in ways meaningful for a variety of stakeholders. Figure 3 illustrates this co-design proposition. It communicates that, if a co-design process starts with alternative plans, sketches, or ideas of sustainable built environments (Step 1), then at the minimum, a socio-spatial typology of real-world urban forms (Step 3) can be employed for the communication of those ideas through typified examples. For example, plan A suggests a mixture of LCZs X and Y, which, based on the empirical LCZ socio-spatial typology, represents N amount of people, provisions for such and such urban commons, and has known implications for the microclimate. Alternatively, an intermediate step can be introduced if more analytical depth is needed, where the proposed plans (Step 1) are assessed for their implications by CPSS (Step 2), before communicating the model outputs in a typology format (Step 3). Both workflows enable an iterative co-design process that is centred on a standardised and accessible language.

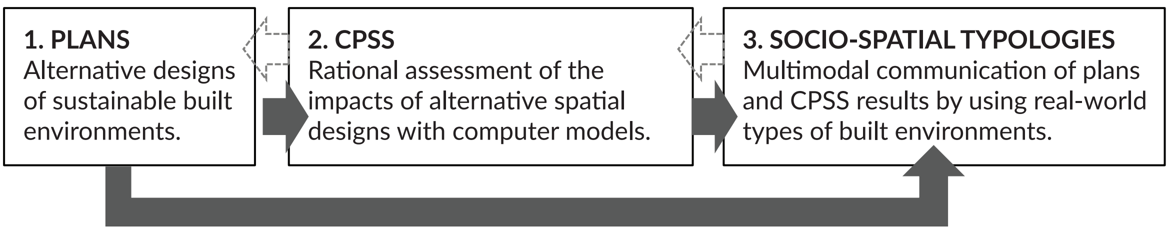


Figure 3. Co-design workflow that utilises CPSS (Step 2) and the socio-spatial LCZ typology (Step 3) as physicalist-rationalist (CPSS) and communicative (typology) planning tools.

Our approach is applicable at various spatial scales because it relies on point or fine-pixel data that can be aggregated to user-specific geometries (e.g., building blocks, postcodes, municipalities, or regions). The most relevant application is at scales between building blocks and neighbourhoods because both the LCZ typology and the urban commons data aim to communicate something meaningful at finer scales of human activity. This approach can be applied worldwide, because it relies on extracting globally and freely available OSM data to map the urban commons components, whereas open-source algorithms can construct the LCZ typology from OSM. Our approach has the potential for broader applications in urban planning. The fusion of formal built environment with informal uses and representations of urban space can facilitate a more comprehensive and accurate mapping of social vulnerability to climate and weather impacts because such data offer integrated insights into the activities and social interactions of people, and where they occur. This can further help to develop better risk and impact assessment models. Lastly, our approach can help to develop tools within the communicative and participatory strands of urban planning. Visual communication of existing and envisioned built environments, which is moreover semantically enriched with subjective representations of urban space, can serve as a common and more nuanced language that engages stakeholders around the kinds of daily life they envision, in which types of urban spaces, and with what microclimatic implications. Borrowing from Jakobson's model of communication (Hébert, 2020) and our current understanding of multimodal communication (Forceville, 2020), our typology enables the communication of messages about urban futures that are both relevant to a variety of audiences and embedded into their pragmatic contexts. It therefore embeds CPSS—as language in addition to a co-design tool—into the broader array of sociocultural functions that languages seek to perform.

Acknowledgments

The first author acknowledges their gratitude to the late Professor Michael Wegener. His work and our discussions served as the inspiration for this study. The authors thank their anonymous reviewers for their invaluable input.

Funding

The research is funded by the Finnish Strategic Research Council at the Academy of Finland (decisions 352450, 352452).

Publication of this article in open access was made possible through the institutional membership agreement between the University of Twente and Cogitatio Press.

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The algorithm and retrieved OSM data are available online at https://doi.org/10.5281/zenodo.14946124

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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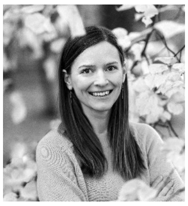

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Urban Planning
2025 • Volume 10 • Article 9509
https://doi.org/10.17645/up.9509

ARTICLE

Open Access Journal

help Them help Themselves: A Toolkit to Facilitate Transformative Community-Based Climate Change Adaptation

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Submitted: 30 October 2024 **Accepted:** 28 January 2025 **Published:** 30 April 2025

Issue: This article is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

Inclusive, co-created strategies are crucial for climate adaptation in vulnerable communities, as they empower local stakeholders to actively participate in decision-making, tailoring responses to specific needs. However, tools that facilitate this collaborative approach are scarce and often inaccessible to under-resourced groups. This article introduces help Them help Themselves (hThT), a web-based tool designed for transformative community-based climate change adaptation (TCbA), which enhances co-creation in adaptation planning. Derived through a combined literature review and key informant interviews, hThT integrates local climate data to offer community-specific, actionable adaptation recommendations. A novel voting feature within the tool allows community members to evaluate proposed measures directly via mobile devices, ensuring broader participation—particularly among women and marginalised groups, who are often restricted by socio-cultural norms and existing power relations. Further, hThT incorporates a reflexive questionnaire that supports facilitators in maintaining inclusive, transparent, and accountable adaptation processes, offering a structured approach to co-creation. Serving as a boundary object, hThT enables shared understanding and collaborative decision-making across diverse groups, bridging governance gaps that commonly impede adaptive planning. Leveraging advances in ICT, hThT aims to enhance the accessibility and usability of climate information, fostering representative decision-making in adaptation planning. By embedding hThT into broader adaptation frameworks, these efforts become more effective and scalable across varied communities, offering a realistic, participatory model for adapting to the uncertainties of climate change.

Keywords

climate change; co-creating adaptation; collective decision-making; community-based adaptation; transformative adaptation; under-resourced communities; web-based tools

1. Introduction

Transformative community-based climate change adaptation (TCbA) is a proactive, co-created approach that empowers under-resourced communities and marginalised groups to adapt to climate change by addressing the root causes that make them more vulnerable than others (Nath, 2024). It leverages the potential of strategic, collective action to address structural inequalities (Ensor et al., 2018). TCbA focuses on communities such as residents of informal settlements in the Global South and shrinking cities in the Global North, who often lack government support due to limited resources, political will, or conflicting priorities. TCbA builds on the established and practiced concept of community-based adaptation (CbA; see Dodman & Mitlin, 2013; Huq & Reid, 2007; Rashid & Khan, 2013; Roy, 2018; Shammin et al., 2021) and emphasises the need to reframe adaptation decision-making by centring it around those most affected, enabling them to actively shape their own strategies along with government and private actors (Nath, 2024). In essence, TCbA aims to facilitate co-created adaptation plans through collective decision-making, ensuring representative participation of all affected groups.

However, in practice, collective decision-making, representative participation, and co-creation face numerous challenges. Historically, decision-making power has been concentrated in the hands of a few, entangled in administrative bureaucracy and information gatekeeping. Gender norms restricting women's mobility often result in their exclusion from collective decision-making processes (Karim & Thiel, 2017). Co-creation, where affected communities and public and private actors collaborate to solve issues like climate adaptation by sharing knowledge and resources (Hofstad et al., 2022), struggles with the challenge of achieving a common understanding and agreement on solutions. Therefore, reframing adaptation decision-making requires interventions that enhance collective decision-making, encourage participation, and foster co-creation. Systemic interventions are needed, particularly by targeting leverage points (Abson et al., 2017). Nath (2024) identified three such leverage points for mobilising TCbA, recognising "changing the structure of information flow" as the most accessible, driven by advances in digitalisation and ICTs. Emerging strategies include the use of web-based digital tools like adaptation option platforms and smartphone apps that enable civic engagement (Karali & Mattern, 2017; Palutikof, Street, et al., 2019b; Street et al., 2019). However, reviews of existing adaptation web-tools (Brzoska et al., 2022; Cavan et al., 2021; Palutikof, Street, et al., 2019b; Shabajee et al., 2014, etc.) show that most are narrowly focused, user-unfriendly, or require specialized expertise. Additionally, these tools primarily provide information on climate change impacts and adaptation without explicitly facilitating participation or consensus-building. In addition, their limited visibility on common search engines like Google or app platforms like Play Store and Apple Store further restricts their usage and the dissemination of their benefits to local communities, particularly those with already limited access to resources such as information, finances, human capital, or government support.

This article proposes a toolkit consisting of a reflexive questionnaire and a web-based decision-support tool: Help Them help Themselves (hThT). Accessible via web browser, mobile app, or as a plugin for existing civic engagement apps, hThT collects local climate data, translates it into actionable insights, and provides tailored adaptation recommendations. These recommendations are based on biophysical simulations of the measures on the built environment and cost-benefit analyses for the affected community, offering a common reference for decision-making. Therefore, acting as a boundary object (Star & Griesemer, 1989), hThT facilitates consensus-building among stakeholders—community members, community-based organizations (CBOs), NGOs/NPOs, municipal officers, and funding agencies. It also proposes a feature novel to adaptation facilitation tools: Each household can access information and vote on adaptation measures via mobile phone, increasing representative participation, which is often limited by power relations and socio-cultural norms (Nath, 2022; Regmi et al., 2016; Reid et al., 2009). Additionally, hThT integrates a reflexive questionnaire (Nath, 2024) to assist facilitators in ensuring an inclusive, transparent, and accountable adaptation process.

The next sections discuss the concept behind hThT, its development process, policy, the governance environment required for the uptake of hThT, and other digital tools that facilitate co-created adaptation.

2. hThT: Using Information as a Resource to Empower Under-Resourced Communities

The current structure of information flow in climate adaptation positions researchers and scientists as the extractors and interpreters of climate data (i.e., the producers, as defined by Lemos et al., 2012). This high-level data is often translated into information and knowledge accessible mostly to experts in adaptation, mitigation, policy, and development agencies. However, information becomes truly usable only when deployed by users in decision-making processes (Lemos et al., 2012, p. 791). Moreover, the data and knowledge produced often cover larger spatial and longer temporal scales that are useful for local action (see, e.g., Wetzel & Mäs, 2022). Adaptation actions are context- and place-specific, affecting specific sets of stakeholders and thus, requiring a knowledge base tailored to local settings (Few et al., 2007).

As a result, despite the apparent abundance of climate information, locally relevant, comprehensible data for non-experts remain scarce. This has been a recurrent barrier to adaptation (Archie et al., 2014; Nath, 2022). On the other hand, advances in digitalisation and access to ICT offer significant potential for general internet users, whether via computers or smartphones, to access vast amounts of information on climate change, its impacts, and possible solutions (Zulkafli et al., 2017). However, to fully harness this information, users must possess "information fluency"—the ability to understand and leverage technology for optimal outcomes (Park, 2017). It is argued that hThT can enable this information fluency by distilling relevant climate information into actionable insights for community members. This is an essential step towards democratisation of information, promoting the inclusion of marginalised groups in selecting problems and their solutions (Buytaert et al., 2014).

Further, in the context of climate adaptation planning, decision-making power has historically been top-down, with central or state governing bodies and funding agencies, often from industrialised nations, holding the power. Meanwhile, those who contributed the least to, and are most affected by, climate change— under-resourced and marginalised groups in emerging countries—often have no voice in this adaptation planning. This imbalance between adaptation decision-makers and beneficiaries frequently results in maladaptation (Schipper, 2020). However, it is argued that meaningful participation can be both a means to address this imbalance and an end, enabling beneficiaries to take a more active role in the process. This can be achieved through greater access to and understanding of adaptation information (Sheppard et al., 2015), facilitated by digital technology (Tappert et al., 2024; United Nations, 2023). Digital information technology, as a boundary object, can be used to break knowledge barriers and facilitate mutual learning in a polycontextual environment, while creating new practice knowledge (Forgues et al., 2010). The internet, as an open and decentralised technology, provides opportunities to create and deliver knowledge through web-based support for users with diverse needs across scales (Zulkafli et al., 2017).

The proposed web tool, hThT, seeks to empower under-resourced communities by using information as a resource to enable informed decisions on adaptation planning and implementation, while also developing their political capabilities. The capacity to access information shifts power from the powerful to the powerless (Park, 2017, p. 166), making it a crucial skill for reframing decision-making processes. Political capabilities here refer to the "political power to shape adaptation decisions" and pursue transformative outcomes, or at the very least, apply enough political pressure to challenge unjust decision-making processes (Holland, 2017, p. 397). One way to exert such power is through co-creating shared systems of learning by doing, which can be put into practice (Giddens, 1984; Newell & Proust, 2017, as cited in Colloff et al., 2021, p. 164). hThT aims to provide this system via a web-tool that both informs users about adaptation measures and facilitates decision-making through mobile-based voting. This is combined with the reflexive questionnaire (Nath, 2024) to ensure an equitable decision-making process from inception to implementation.

hThT focuses on facilitating the continuous process of adaptation, not just the outcome, since as climate change progresses, more unknown than known consequences will emerge (Schipper, 2020). Therefore, hThT doesn't aim to provide only one-off solutions but to facilitate communities in preparing for these uncertainties by developing their capacities to self-organise and use relevant climate information to adapt. This also informs hThT's definition of successful adaptation, which is not about determining when a community is considered adapted but about ensuring the development of adaptive capacity within the community. This is achievable only when the community is equipped with the necessary tools to adapt to evolving conditions, relying on key skills such as digital and information literacy, self-organisation, and the ability to assert political agency. This also includes continuous and deliberate efforts to address structural issues. The hThT reflexive questionnaire aims to facilitate these deliberate efforts through a list of diagnostic questions for each step of the adaptation process that ensures all relevant actors and stakeholders are cognisant of the need to create an inclusive strategy that respects the needs of all groups (Nath, 2024). Figure 1 shows the use of the hThT tool set along a typical (T)CbA process.

The characteristics of the web-tool are based on a two-step methodology (see Figure 2): a literature scan of existing digital and web-based adaptation tools aimed at non-experts, and insights gathered through interviews with key informants.

2.1. Characteristics Derived From Literature

The following are key insights from relevant literature on decision-support frameworks (e.g., Denzer et al., 2011; Leitch et al., 2019; Palutikof, Leitch, et al., 2019; Street et al., 2019; Zulkafli et al., 2017) and digital tools (e.g., Brzoska et al., 2022; Cavan et al., 2021; Deas, 2015; Fisher et al., 2018; Palutikof, Street, et al., 2019a, 2019b; Shabajee et al., 2014), especially those facilitating adaptation decisions, to inform the development of hThT:

1. Socio-cultural context: Tools must consider the socio-cultural context of their end users, including capabilities, time, and resources, to ensure accessibility and effectiveness (Palutikof, Street, et al., 2019a). Socio-cultural norms may influence tool adoption, and tool design should be mindful of potential barriers for specific groups, such as gender-based constraints, "accounting for its historical embeddedness in social practice" (Wolfram & Vogel, 2012, p. 326). Understanding the perspective of the targeted end-users and contextualising information provided based on the socio-cultural context

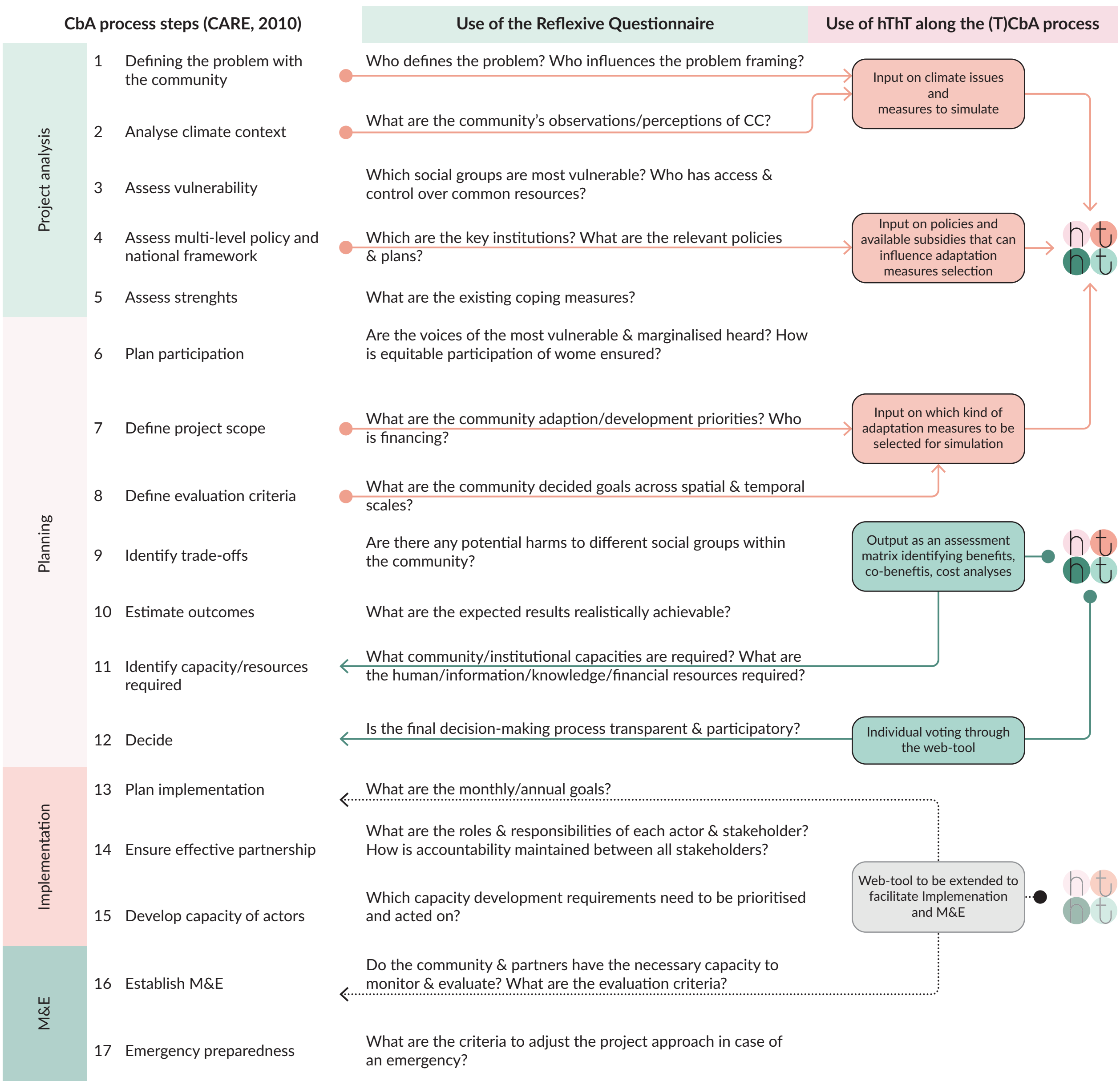

Figure 1. Using hThT web-app and reflexive questionnaire along the (T)CbA adaptation process. Note: The use of hThT in the implementation and M&E phase is envisioned and not described in this article. Sources: Reflexive questionnaire adapted from Nath (2022, 2024); (T)CbA cycle adapted from CARE (2010).

of the tool is crucial for both implementation and evaluation of impact (Brzoska et al., 2022; Street et al., 2019).

2. Defined spatial and temporal scale: Tools must be tailored to the appropriate scale for action-takers (e.g., individual or community), providing micro-level or neighbourhood-specific information (Brzoska et al., 2022; Palutikof, Leitch, et al., 2019). Adaptation measures should be implementable at the relevant scale, and the tool should address local knowledge, trade-offs, and varying granularity of information and expertise(Fisher et al., 2018).
3. Ease of use and actionable outputs: For non-expert users, it is helpful to have comprehensive outputs and actionable information that resonates with their needs (Deas, 2015), especially monetary values, in

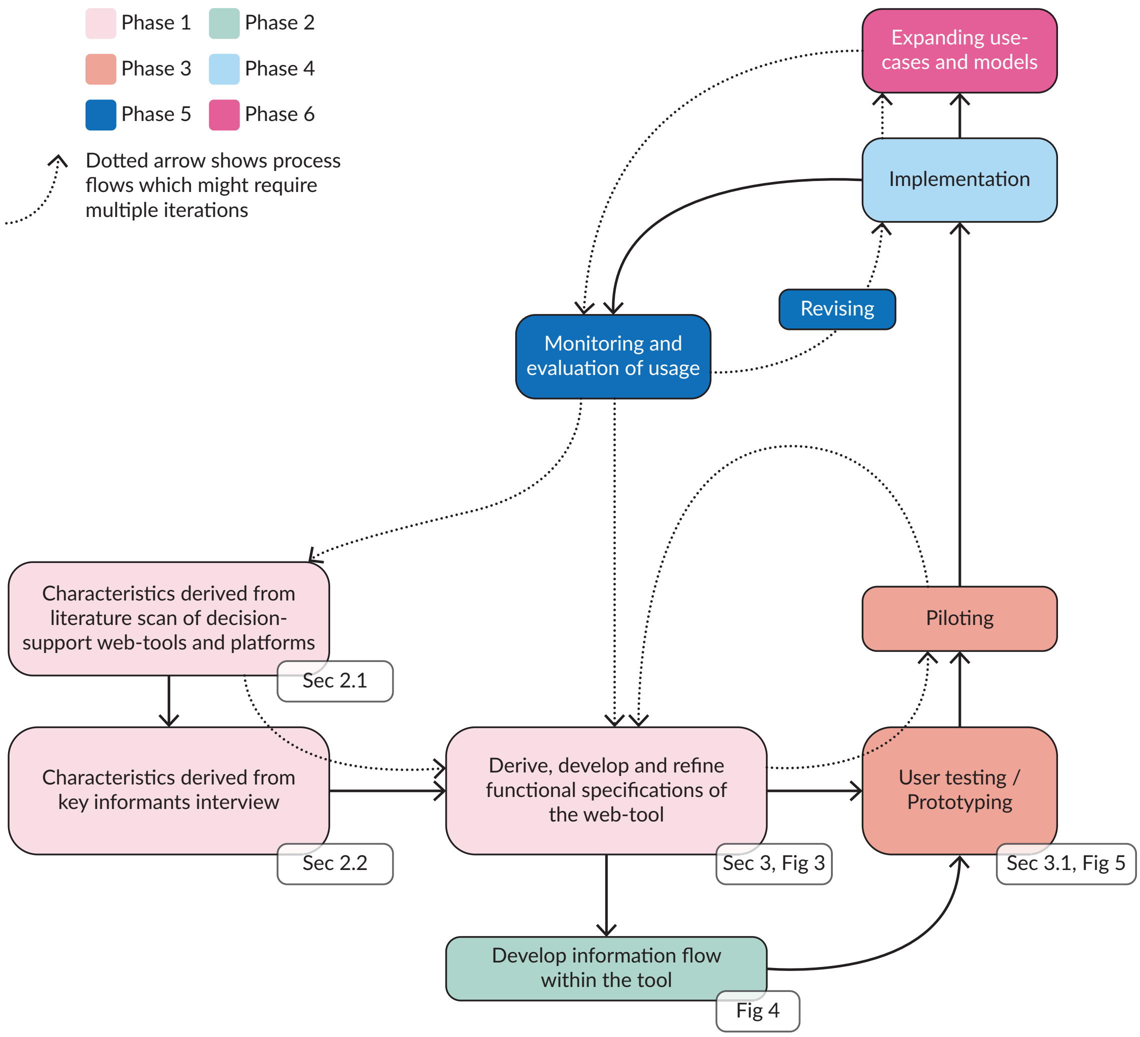

Figure 2. hThT web-tool development process. Notes: Various phases of development are represented in this process; this article is limited to the first part of phase 3—user-testing/prototyping.

order to convince funders (Brzoska et al., 2022), and gather consensus among the local action-takers. Tools requiring minimal input data and offering easy navigation increase usability (Brzoska et al., 2022; Cavan et al., 2021; Deas, 2015; Wetzel & Mäs, 2022). This should be complemented with simple language and user-friendly interfaces (Haße & Kind, 2019; Palutikof, Street, et al., 2019b).

4. Multiplicity and flexibility of use: Tools should define clear user groups (Cavan et al., 2021; Denzer et al., 2011) and be designed for diverse needs and decision-makers (Zulkafli et al., 2017), addressing climate impact as one of many stressors (Lemos et al., 2012). Using open-source data, modular designs, and the ability to update models help address the one-size-fits-all challenge (Brzoska et al., 2022; Palutikof, Street, et al., 2019b).
5. Evaluate adaptation options and trade-offs: Tools must help users evaluate adaptation options, link them to impacts, and assess trade-offs and co-benefits (Stratus Consulting Inc., 1999, as cited in Cavan et al., 2021).
6. Facilitate participation and consensus building: Tools should promote engagement and participation (Haße & Kind, 2019), particularly among marginalised groups within a community. This may require strategies such as focused group discussions rather than open forums (Rosengren et al., 2020).

7. Institutionalisation: Adaptation tools need rhetorical force—users must trust the information and recognise its authority, which comes when the tool is institutionalised within policy and multi-level decision-making (Deas, 2015). The credibility of the tool relies on expert validation and state endorsement (Palutikof, Leitch, et al., 2019). Ownership by a recognised institution further strengthens uptake; however, civic intimacy between citizens and the institute also influences uptake (Praharaj et al., 2017).
8. Inter-organisational application: For effective implementation and securing funding, the tool must facilitate inter-organisational data exchange, such as between municipal departments (Wetzel & Mäs, 2022).
9. Integration in existing workflows: Tools are more likely to be adopted when they complement existing knowledge and routines (Fisher et al., 2018). Information that adds value to current processes is more usable and easier to integrate.
10. Maintenance and serviceability: Continuous guidance and support are crucial during both development and application (Street et al., 2019). Identifying communities of practice and boundary organisations helps users navigate the tool and avoid adoption barriers (Fisher et al., 2018; Kalafatis et al., 2015; Palutikof, Street, et al., 2019a). Regular updates are necessary to maintain user trust.

2.2. Characteristics Derived From Key Informant Interviews

Building on the insights from the literature review, key informant interviews (KIIs) were conducted to gather user perspectives. The KII approach allows researchers to understand how target communities—here, the users of the web-tool hThT—experience and perceive the tool, providing insight into a broader range of end uses and useful features (Cossham & Johanson, 2019). While a grounded co-creation process is argued for developing web-tools due to the limited feasibility of the current research, a KII approach is used for "practical insider knowledge and are interviewed as surrogates for a wider circle of players" (Bogner et al., 2009, p. 2).

Interviewees were identified from potential user groups, including community members, researchers, practitioners in CbA, NGOs/NPOs working with under-resourced communities, and government officials.

Community members were interviewed from a test case site in an informal settlement in South-West Delhi. This was also accompanied by a survey of their neighbourhood-built environment in December 2023. Two individuals, who chose to remain anonymous, shared their perceptions on the need for adaptation, their experiences with government-managed mobile apps for citizen engagement (e.g., Swacchata-MoHUA, MCD app), and their thoughts on integrating grievance redressal with adaptation planning in a web-tool.

Researchers and practitioners provided insights into the barriers they faced in implementing community-based interventions, their experience with community participation, and their feedback on the potential usability of a web-tool. Interviewees included Sushila Pandit, a researcher at the Global Challenges Doctoral Centre, University of Kent, and Richard Taylor, Senior Research Fellow at the Stockholm Environment Institute, London. Pandit has over a decade of experience in climate change through her work with national and international organisations like CARE, Practical Action, and Mercy Corps. Taylor specialises in climate adaptation tools and decision-making processes.

In the NGO/NPO category, the director, Renu Khosla, and Barsha Poricha of the Delhi-based CURE were interviewed. CURE works with informal and low-income urban communities to develop solutions that integrate them into city development processes, including web-based applications for collecting and integrating community data.

One practitioner, Preeti Prada Panigrahi, an urban social policy strategist who, at the time of the interview, was leading the slum upgrading project JAGA Mission in Odisha, and a retired government official, Pradeep Kumar Khandelwal of the East Delhi Municipal Corporation, also provided valuable insights.

Three key themes were identified to guide the interviews and analysis: Climate adaptation awareness in the communities involved; participation in decision-making—whether present or absent and to what level; and feedback on the envisioned web-tool. Interviews were conducted either in person or via video, lasting between 45 and 60 minutes each. The interview guide can be found in the Supplementary File 1.

The following key requirements were extracted from the interviews:

1. Ownership and serviceability: To ensure widespread adoption and legitimacy, interviewees stressed that the tool should be centrally owned by the government, allowing for cross-state and municipal use. This echoes findings from the literature (points 8 and 10 in Section 2.1). Central ownership ensures long-term reliability, updates, and support—balancing top-down control with bottom-up use.
2. Avoiding an "app graveyard": While apps like the Swacchhata Platform (https://www.swachh.city) have been successful, there is concern about creating an "app graveyard" of abandoned platforms. Panigrahi suggested a modular approach, integrating climate services into existing civic engagement platforms to avoid overwhelming users with competing apps.
3. Identifying champions: Considering the socio-cultural context of application, identifying community champions—such as young people—was recommended for promoting tool uptake. These champions could be trained to use the tool and then help raise awareness within their communities.
4. Orientation and sensitisation: To address digital literacy challenges, periodic workshops were recommended. Trained champions could autonomously run these sessions. Additionally, the tool's user interface should remain simple and free of jargon to ensure accessibility.

2.3. Features of the hThT Web-Tool

Figure 3 presents a matrix linking requirements derived from the literature and KIIs with the features of hThT, assessed at varying confidence levels (low, medium, high). It illustrates how these features operationalise the characteristics of TCbA. For instance, the proposed hThT architecture meets the requirement of "evaluating options, trade-offs, and co-benefits" with high confidence, as it enables the collection and translation of climate science into actionable insights, displayed in an assessment matrix of co-benefits and trade-offs (see also Figure 5, screen (g)). By providing climate-informed decision support, it empowers communities, granting them agency for adaptation action and fostering learning (TCbA characteristics 2 and 5; see Figure 3). Additionally, simulating the effects of selected measures on local environments aids consensus-building (TCbA characteristic 4). While rooted locally, science-backed decisions enhance community voices across administrative levels, facilitating greater representation (TCbA characteristic 3). Other requirements, such as "addressing socio-cultural context," are collectively met with medium

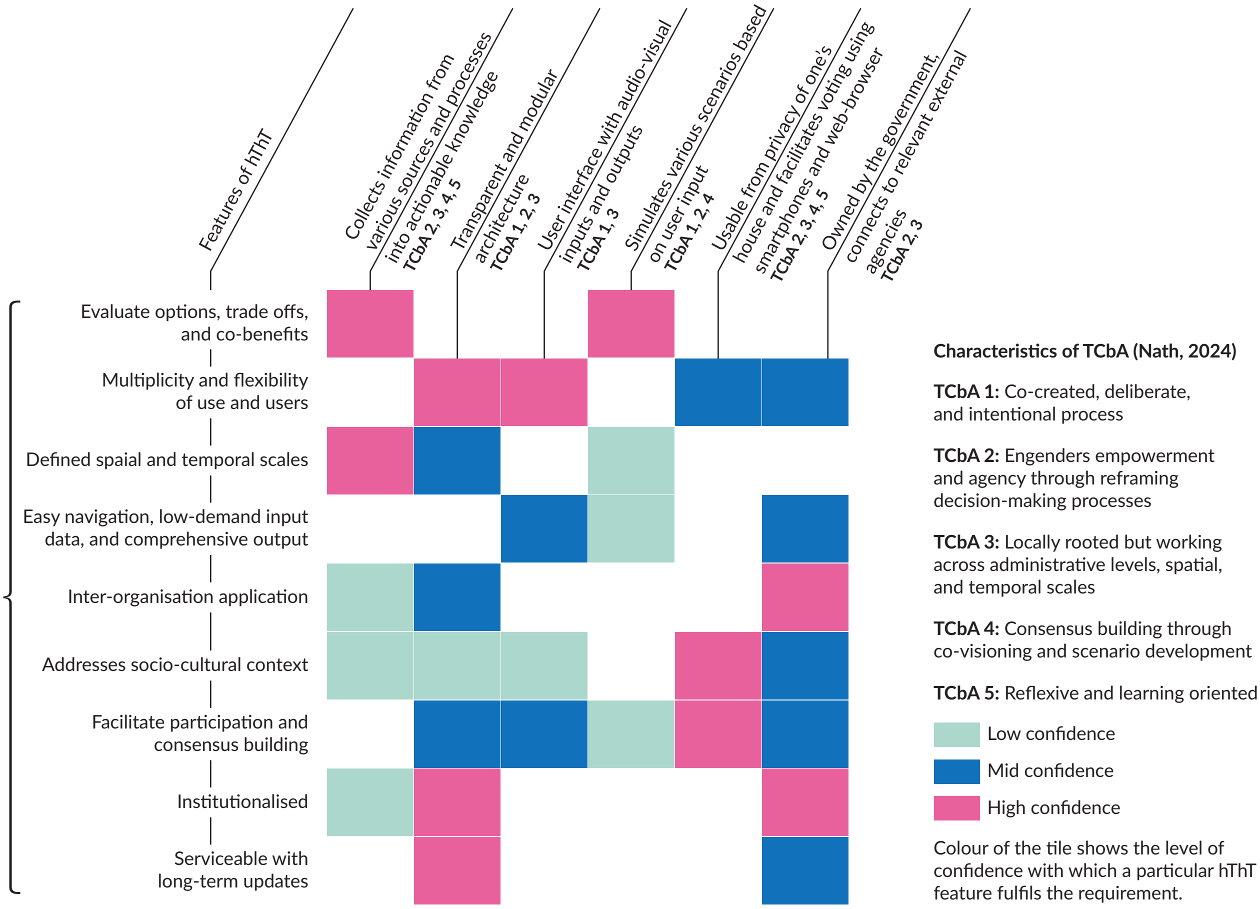

Figure 3. Features of hThT web-tool. Source: Nath (2024).

confidence. In addressing norms and power dynamics in decision-making, the tool introduces a high-confidence, novel feature for voting on adaptation measures based on the assessment matrix, also meeting the requirement of "facilitating participation and consensus building." This feature, "usable from the privacy of one's home via smartphones or web-browsers," further empowers community members (TCbA characteristic 2) by enabling equitable participation in decision-making, regardless of gender or socio-economic background.

As discussed in Section 2.1, some of these features build on the characteristics conceptualised and/or implemented in tools like the one conceptualised by Brzoska et al. (2022), who emphasised the need to include microclimatic simulations and develop a tool that can support non-scientific communities, such as planners, but also private users. hThT also furthers the feature of modularity, designing for multiple uses and enabling participation, as suggested by Haße and Kind (2019), while updating the Klimalotse (climate navigator) tool for use in public institutions and their decision-making processes. However, hThT distinguishes itself from these and other existing tools, such as CoastAdapt (Leitch et al., 2019) or STAR tools (Cavan et al., 2021), through its focus on being comprehensible and accessible to non-experts, particularly private users, and by advancing the use of online voting to ensure representative and meaningful participation. In addition, conceiving hThT both as a plug-in and a stand-alone tool is a novel feature.

3. hThT Web-Tool: Information Architecture

The hThT web-tool has been envisioned as a co-created web-tool, i.e., while an institution may own or host the tool to legitimise it (point 7 in Section 2.1), its development and evolution are deeply influenced by ongoing input and contributions from the community it serves. Therefore, the proposed information architecture uses an open design approach. An open design is defined as "the state of a design project where both the process and the sources of its output are accessible and reusable by anyone for any purpose" (Boisseau et al., 2018, p. 17). This approach also allows the design to be freely shared, collaborated on, or prototyped by communities or individuals.

Its overall architecture comprises a front-end user interface and a set of back-end tools or analytical modules, like data sets for location and 3D model data or adaptation measures; connected via a centralized system for data storage, definition, and delivery (see Figure 4, point (a)). This architecture allows hThT to have a modular development of solutions tailored to specific locations and adaptation challenges. Different components can be modified to fit the adaptation needs of specific neighbourhoods (Figure 4, point (b)). For instance, based on the climatic region and geographic location of the neighbourhood, issues like heat, drought, or flooding can be added or removed, and the recommend adaptation measures updated. Similarly, simulations and software can be adjusted based on the geophysical phenomenon and the level of detail required for the task. Different software applications (like ENVI-Met, IDA-ICE, etc.) for varying relevance and accuracy of 3D model development and subsequent simulation—for example, outdoor thermal comfort, stormwater run-off analysis, indoor thermal comfort, etc.—can be easily plugged in and independently developed. The modularity of these components also allows for updates with new information and as adaptation science progresses. It is envisioned that with such a modular design based on the principles of open design, the tool will be adopted by communities of practice, like researchers and practitioners working on local adaptation, ensuring its maintenance over time.

Additionally, hThT can be integrated with other citizen engagement tools or used as a standalone web tool. The granularity of information and its delivery method are flexible, catering to different user needs. More detailed information, for example, simulation details, can be accessed by experts for verification and replication (Figure 4, point (c)), while community decision-makers can choose to directly see actionable information, like the assessment matrix (see Figure 5, screen (g)).

The tool is both demand- and feedback-driven, providing new information based on community-identified needs. For example, communities can request the development of neighbourhood models for specific adaptation measures (see Figure 4, point (a), and Figure 5, screen (c)). This flexibility allows hThT to expand its geographic coverage as new neighbourhoods require assessment. Additionally, the front-end interface and language can be customised for different user groups—whether residents of an informal settlement (e.g., the test case in India) or a municipal officer in a small under-resourced municipality, for example, in peri-urban Germany. To accommodate varying levels of digital literacy, the interface includes explanatory visuals and audio input/output options, ensuring inclusivity in co-creating adaptation plans.

The front-end displays results in the form of assessment matrices, voting options, and visualisations accessible via smartphones, laptops, or citizen engagement apps (see Figure 4, point (d)). The option for e-voting minimises the influence of powerful community members, which often skews physical group voting

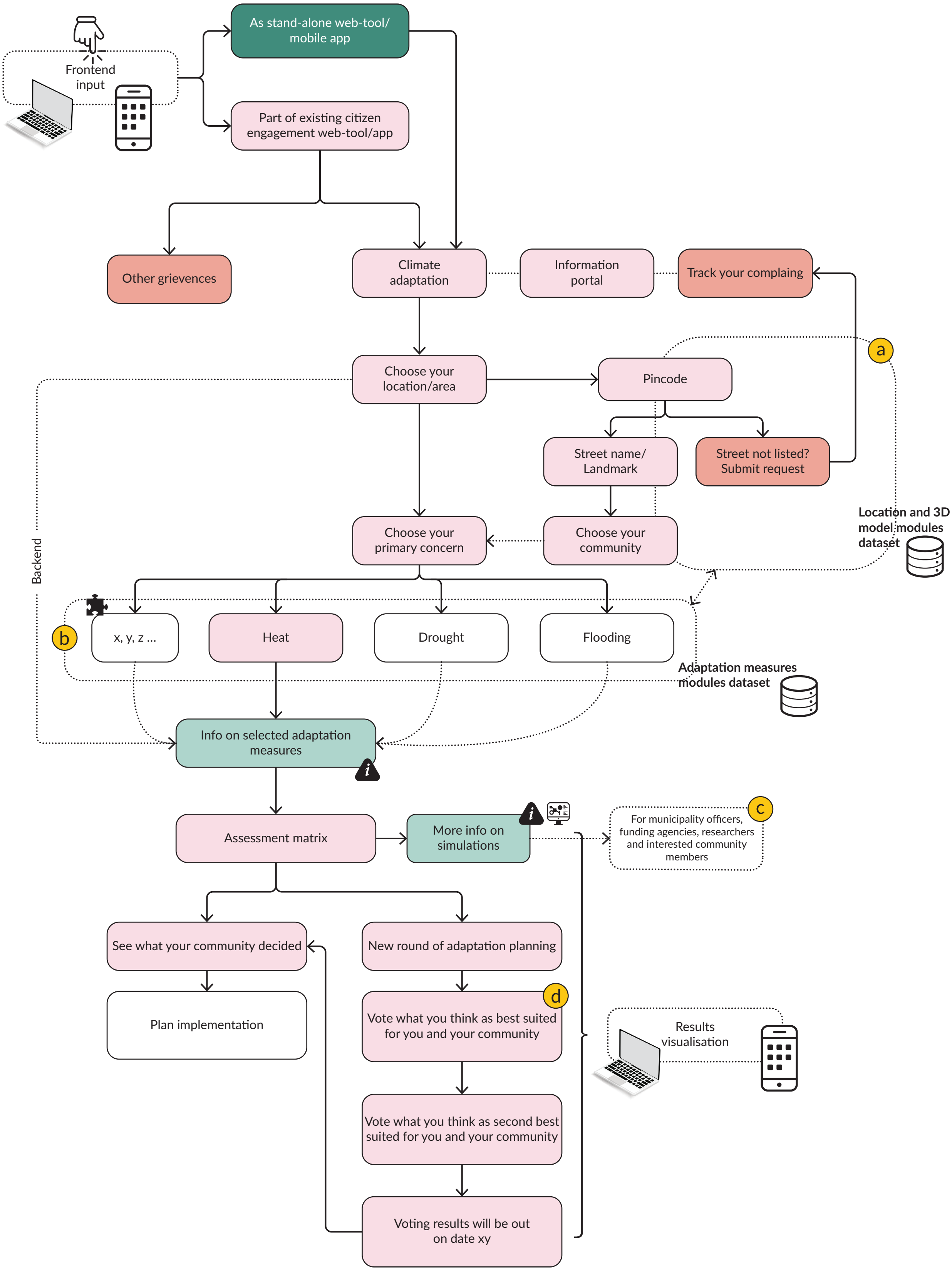

Figure 4. hThT web-tool information architecture. Key points are highlighted: Point (a) highlights the analytic modules; point (b) the flexible adaptation modules; point (c) leads to extra information on simulation details, like model boundary conditions, etc.; point (d) highlights the voting feature.

results. E-voting also enables participation from groups who might otherwise be excluded due to socio-economic norms, allowing them to vote from home.

3.1. Prototyping hThT in an Informal Settlement in Delhi, India

To evaluate the usability and comprehensibility of the tool, a mobile app prototype was developed using a trial version of the web-based prototyping software Proto.io (https://proto.io). The user interface was designed to be simple, requiring minimal input from users (see point 2 in Section 2.1), with information on possible adaptation measures available in the local language and with audio output options at each step. The prototype focused on heat adaptation, with the assessment matrix showing hypothetical values of improvement in outdoor and indoor thermal comfort, and the cost per sq. ft. of applying this measure (see Figure 5, screen (g)).

The prototype mobile app was shown to the community, who had been consulted as key informants during the initial development. Their feedback was mixed. They found the user interface usable after an initial explanation,

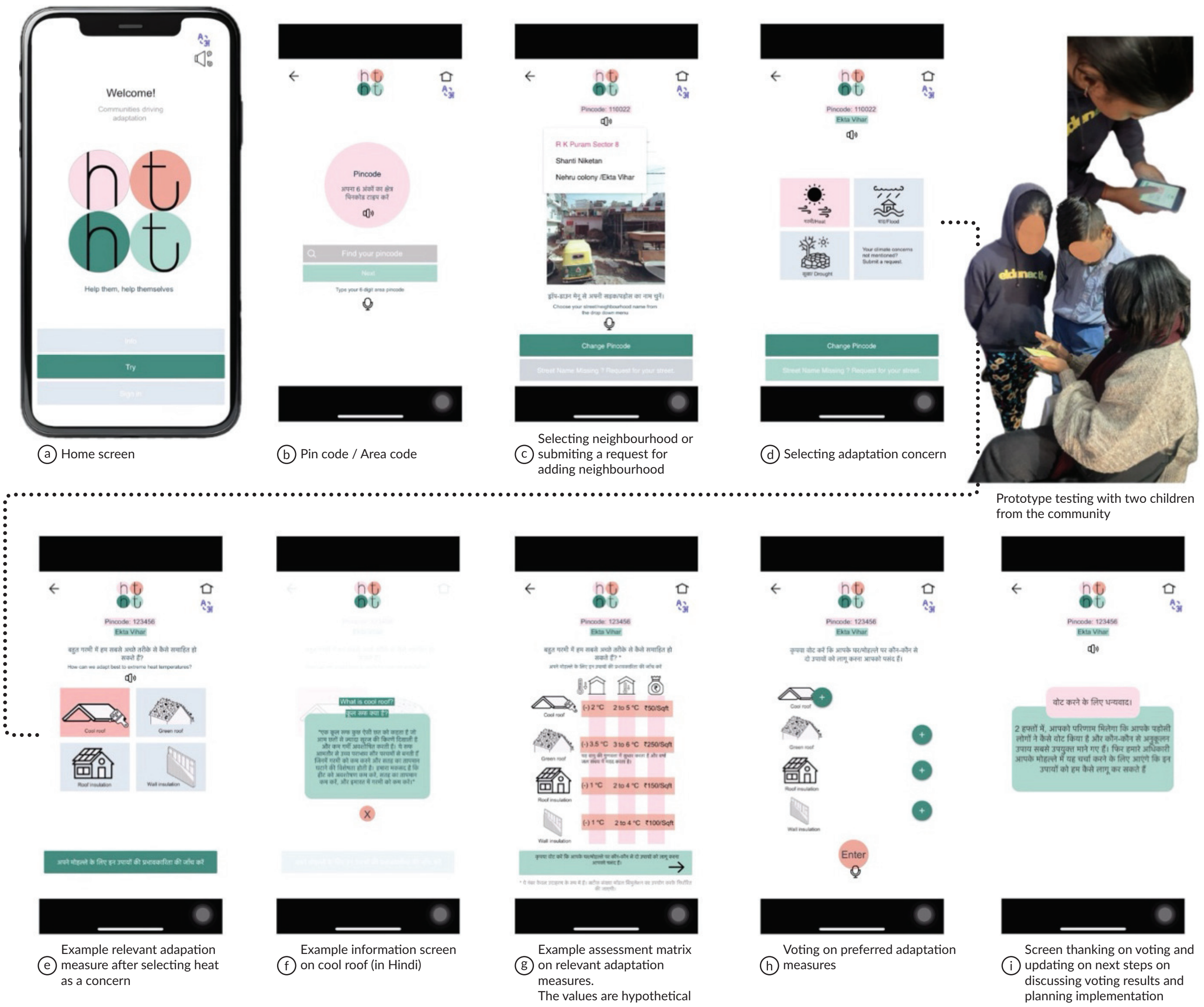

Figure 5. hThT Smart Phone App Prototype.

but they suggested integrating voice input, as many community members were non-readers and relied on visuals and audio. The prototype only included voice output. However, when asked if they would use the app if made available via smartphone app stores, the community responded: “Come back in a few weeks. We can’t think of these things when we have just received an eviction notice.” This reaction was not entirely unexpected, as climate change is just one of many challenges the community faces and is often not their top priority (Lemos et al., 2012; Reid et al., 2009, p. 13).

While there were precedents that suggested this eviction notice would not be acted on, the fear persists and deprioritised adaptation concerns. Due to time constraints, the community was not consulted again, raising important questions about the usability of such adaptation tools. Specifically, when can these tools intervene in informal settlements? How do these contexts change? What policy and governance environments are needed for the uptake of hThT and other adaptation tools? The next sections explore these questions.

4. Points of Intervention: When and Where Is hThT Applicable?

The hThT tool set, including the web-tool and the reflexive questionnaire, was developed in response to the need for a practical solution to mobilise TCbA. TCbA offers alternative pathways to address the multidimensional challenges faced by under-resourced communities (Nath, 2024, p. 5). These challenges vary depending on whether the community is resource-deprived, as in informal settlements, or resource-scarce, as in shrinking cities.

To understand how hThT can facilitate adaptation in informal settlements, it is crucial to consider the typical lifecycle of such settlements, which progresses from informal land occupation without basic services to becoming a formal settlement recognised and supported by state authorities (Du Plessis et al., 2016). Several steps are taken along this continuum, as outlined in Figure 6, which shows the common trajectory of informal settlements in India (referred to as slums). hThT can intervene at two key stages. The first is after the settlement has been officially recognised as a “slum” and as it continues to grow. During this phase, hThT can be employed by the community, facilitated by NGOs and CBOs, to adapt to climate stressors, often by securing essential services. For instance, securing a regular water supply, while a basic necessity, is crucial for coping with heat. Similarly, green roofs can help harness rainwater and improve thermal comfort. hThT, through its location-specific simulation of current and adapted conditions, along with cost-benefit analyses, provides evidence to demand funding and support for implementing these measures. Most adaptation measures at this stage will be limited to short-term, low-cost options due to the absence of tenure rights and the ongoing threat of eviction. The second possible intervention point is to co-create a climate-resilient slum upgrading plan, involving the community, state authorities, and public or private funding and implementing agencies. This intervention is crucial, as most slum upgrading plans do not currently incorporate climate resilience and tend to involve only tokenistic participation (Satterthwaite et al., 2020). By combining the hThT questionnaire and web tool, the process allows for reflexive and inclusive participation and provides a platform for individuals to vote on their preferred adaptation and upgrading measures. In resource-scarce shrinking cities, depopulation and consequent economic decline have reduced municipal budgets and capacities for climate adaptation. This often leads to a lack of urgency and political will to address climate-induced stressors. Concurrently, there is a trend in European Union countries toward civil service reform and decentralisation of public tasks. Citizens are increasingly expected to take on roles that were

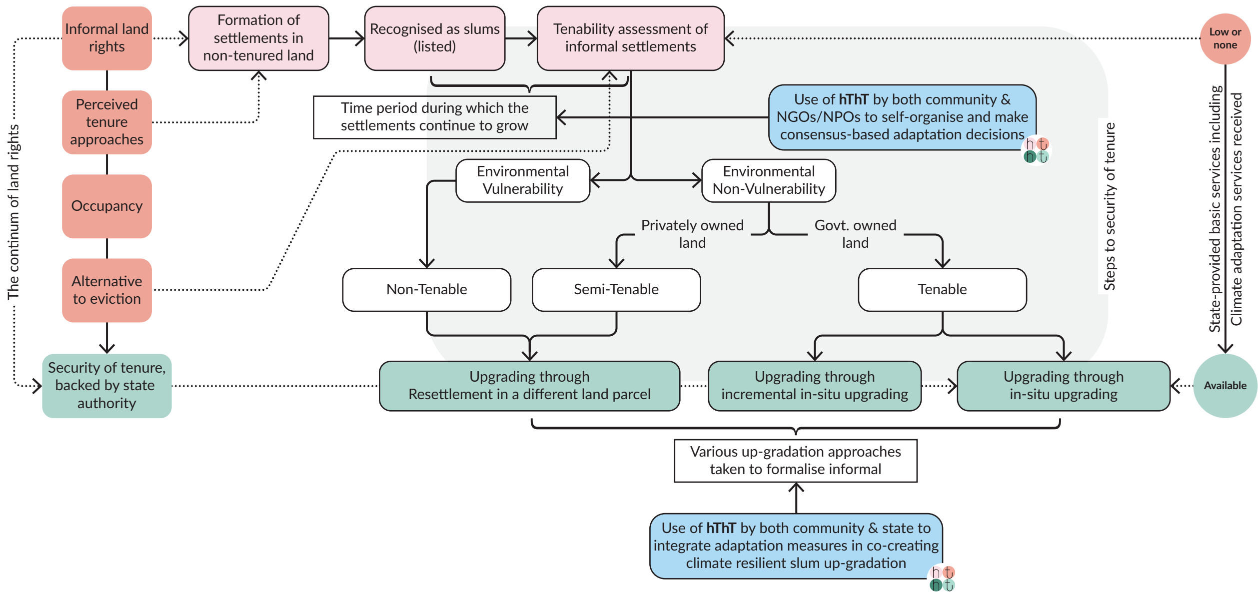

Figure 6. Typical intervention points in an informal settlement.

previously public services, and in turn, are more interested in being involved (Korthagen et al., 2018). This creates an entry point for hThT to act as a transparent platform for co-creating adaptation strategies and sharing responsibilities among citizens and private and public actors.

By providing tailored simulations of relevant adaptation measures, using locally specific climate data, hThT enhances trust in the proposed solutions without adding capacity burdens. hThT can also provide information on relevant funding policies to support the implementation of these measures. The lack of updated information on which funding measures can be used for implementation and the lack of capacity to identify viable solutions are two key issues raised by municipal officers in the German states of Saxony, Saxony-Anhalt, and Thuringia (Höhle et al., 2022). Furthermore, hThT's participatory framework, user-friendly interface, and options for audio input, output, and multiple languages ensure that even those with limited digital literacy can engage. This broadens participation, making decision-making more inclusive and equitable.

However, these interventions for co-creating adaptation strategies can only succeed if complementary policy and governance structures are in place, as discussed in the next section.

5. Required Environment for the Uptake of hThT

The uptake of hThT and other digital technologies for facilitating co-creation of adaptation planning and implementation strategies relies first on public policies and governance structures, and secondly on public awareness and readiness to participate in these processes. Coherence between climate policies and policies on e-governance, devolution of power to the local level, digitalisation, participation (offline and digital), and funding is crucial. Casiano Flores and Crompvoets (2020) emphasise the lack of coherence between various governance elements that leads to policy failures. Gaps in policy integration lead to poor coordination between institutions and involved actors across administrative levels, resulting in ineffective partnerships and unsustainable community-driven projects (Piggott-McKellar et al., 2019). Coherence (or the lack of it) is among five key qualities of governance that can be assessed to determine whether the current governance structure is supportive or restrictive of the uptake of hThT and other adaptation tools (Casiano Flores & Crompvoets, 2020).

While most adaptation action occurs at the local level, policies are often discussed at the national and state levels. For instance, a recent scholarly appraisal of climate adaptation policies and governance in India did not mention any local-level adaptation planning (Pandey et al., 2024). Without a commitment to integrating locally led adaptation planning into national policy, along with dedicated resources at the local level, funding for adaptation will continue to support top-down, centralised activities that struggle to address the needs of vulnerable communities (Remling & Veitayaki, 2016, as cited in Nath, 2022). This leads to a lack of reliable, long-term financing needed to maintain tools like hThT, operating at the local level.

In India, existing policies on decentralisation, such as the 73rd Constitutional Amendment Act and state finance commissions, along with the National e-Governance Plan (Ministry of Communications, 2006) and National Policy on Information Technology (Ministry of Communications, 2012), theoretically provide a strong foundation for hThT uptake. However, in practice, local governing bodies' power remains "residual" and depends heavily on political will (Mohapatra, 2012). A decade later, Mohapatra (2022) reports that the devolution of functions and functionaries has not yet been fully implemented, leaving local self-governing bodies financially dependent on state governments. Additionally, resources must be allocated for capacity building at the local level. Based on observations from municipalities in East Germany, Tafel et al. (2024) argue that without adequate resources, even municipalities with high awareness and motivation fail to actualise adaptation. These capacities can range from human resources and knowledge of relevant funding policies to integrating digital technologies, such as web-tools, into established workflows.

The uptake of hThT and similar tools facilitating community-based adaptation is also vulnerable to path dependence, which may act as a barrier to institutional change by locking them into specific patterns of thinking and decision-making. Such path dependence reduces their ability to adequately or meaningfully respond to evolving problems like climate change and may make them reluctant to respond to the emergence of new imperatives (Matthews et al., 2015).

On the other hand, public engagement also remains a challenge, despite growing awareness. In India, this is particularly due to the stratified and complex socio-economic and political context, power imbalances, and the inadequacy of decentralised governance structures. These factors complicate access to the information needed for civic decision-making (Menon & Hartz-Karp, 2019). In urban areas, however, growing public discontent with government decision-making has led to increased interest in community participation and partnership in civic decision-making (Menon et al., 2021). Citizens have expressed a readiness for partnerships, third-party facilitation, and support from civic advocacy groups (Menon et al., 2021). A similar trend is observed in European countries, where citizens are increasingly eager to participate in decision-making. However, challenges persist in this context as well. Participatory and e-participative projects provide personal value for participants and enhance community capacity but often lack direct or indirect political impact (Korthagen et al., 2018). For example, Swedish municipalities have noted a disconnection between citizen participation and climate adaptation in policy documents, which can discourage future civic involvement (Glaas et al., 2022).

Civic involvement is also influenced by who owns e-engagement platforms and web-tools, with those assigned prominent roles in local government being more widely used (Kumar et al., 2013). Civic intimacy also influences the uptake of these tools and platforms. While abilities and digital skills are important influencers, citizens' awareness and interest play a larger role (Praharaj et al., 2017). Further, to create a supportive environment for the uptake of hThT there must be clear pathways showing how local civic participation outcomes are translated into policies at different levels. Mees et al. (2019) argue that the increased responsibilities placed on citizens also affect government roles. While government involvement may not decrease, its role must evolve from a regulatory and directive approach to one that is more collaborative and adaptive, enabling and supporting community-led initiatives that are self-managed by citizens.

6. Conclusion and Outlook

This article proposed a toolkit to mobilise TCbA. The toolkit comprises a web-tool to facilitate co-creation of adaptation strategies and a set of diagnostic questions designed to assist on-ground facilitators in being reflexive about the socio-cultural context in which adaptation planning and implementation will take place. The information architecture of the proposed web-tool, which follows an open-design approach, is presented along with a smartphone app prototype. The web-tool, accessible by smartphones or computer web browsers is designed to facilitate the co-creation of adaptation strategies by ensuring representative and meaningful participation of community members of all genders, ages, and socio-economic backgrounds in the decision-making process. It can be a stand-alone app or integrated into other citizen engagement apps. Findings from KIIs and existing literature highlight the critical need to embed the toolkit directly within the TCbA process, ensuring it is contextualised rather than viewed as a universal solution. Effective adaptation requires not only the provision of digital tools but also a holistic framework that integrates these tools into established community practices and governance structures. Further, the hThT platform has the potential to serve as a boundary object, capable of bridging organisations and stakeholders from different communities of practice, while enhancing communication across policy domains and governance levels involved in climate adaptation.

The integration of climate services within a digital public services model, as part of the recent UN's Digital Public Infrastructure approach (United Nations, 2023), underscores the broader potential of digital adaptation tools. Developing monitoring and evaluation features, real-time collaboration, and expert support options could expand hThT's capacity as an adaptive governance resource, ultimately enhancing the co-creation of strategies. However, the toolkit's effectiveness will rely on evolving it to support the consolidation of individual decisions into coherent, community-driven actions—a complex process that, as noted, cannot be simplified into input-output models (Biesbroek et al., 2015). Therefore, a notable limitation of the proposed toolkit is the challenge of consolidating individual perspectives into collective decision-making. The process of moving from personalized preferences to collective action remains intricate, influenced by socio-political dynamics and imbalances in decision-making power. The hThT toolkit, while advancing accessibility and inclusivity, is not positioned as a comprehensive solution to all public decision-making complexities. While the toolkit incorporates a reflexive questionnaire to engage with these internal dynamics, more extensive, ongoing community engagement remains crucial. Adapting the toolkit to diverse socio-political contexts remains a challenge. While hThT's modular design and multiplicity of uses render it conceptually adaptable, its practical uptake and efficacy will ultimately depend on the specific realities of different settings. For instance, the rapid and unplanned urbanisation of cities in the Global South contrasts sharply with the challenges of shrinking cities in the Global North, highlighting the need for tailored implementation strategies.

Overall, hThT offers a foundation for collaborative adaptation, yet future work must prioritise frameworks that accommodate community needs through iterative co-design, continuous improvement, and, ultimately, empowerment in adaptive governance.

Acknowledgments

This research would not have been possible without the generous contributions of time and feedback from the community members who supported me during the fieldwork and participated in the interviews. I am deeply grateful to the key informants for their invaluable insights: Sushila Pandit, Richard Taylor, Renu Khosla, Barsha Poricha, and Pradeep Kumar Khandelwal.

Funding

This research was supported by the funding received from Dresden Leibniz Graduate School—a joint interdisciplinary facility of the Leibniz Institute of Ecological Urban and Regional Development (IOER) and TU Dresden. Publication of this article in open access was made possible through the institutional membership agreement between the University of TU Dresden and Cogitatio Press.

Conflict of Interests

The author declares no conflict of interests.

Data Availability

Appendix 1 provides details on the interview guidelines. Additional data and materials not included in the appendix are available upon request.

Supplementary Material

Supplementary material for this article is available online in the format provided by the author (unedited).

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Urban Planning
2025 • Volume 10 • Article 9519
https://doi.org/10.17645/up.9519

ARTICLE

Open Access Journal

A Decision Support Model for Assessing Co-Creation: The Bee Path Project

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Submitted: 29 October 2024 **Accepted:** 11 March 2025 **Published:** 19 May 2025

Issue: This article is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

This article presents a decision support model (DSM) for assessing the quality of co-creation processes and critically reflects on its applicability in the context of climate change mitigation in urban settings. While cities have become pivotal in addressing climate change, often through co-creation, tools for evaluating urban climate-related co-creation initiatives remain scarce. Rather than advocating for a tool specifically designed for this context, the article seeks to offer a universal DSM developed through a systematic literature review and empirical case studies within the framework of the COGOV Horizon project. The DSM incorporates 19 attributes across three phases of co-creation: stakeholder identification and mobilisation, the act of co-creation, and its effects. The model is tested on the Bee Path initiative of the City of Ljubljana, a successful co-creation project aimed at fostering a bee-friendly urban environment and promoting self-sufficiency. The results confirm the DSM's applicability in assessing the success of co-creation in the context of climate change policies at the city level of governance. Moreover, this tool offers a foundation model for further integration with emerging technologies to enhance decision-making and guidance for public organisations. As such, the DSM serves as a practical tool enabling public organisations to critically reflect on their roles in co-creation initiatives, identify areas for improvement, and enhance their capacity as co-creators in future urban climate policies and beyond.

Keywords

climate change; co-creation; decision support model; Ljubljana; quality assessment

1. Introduction

Climate change is a pressing global challenge with severe consequences, yet it only gained formal international recognition in the 1990s (Rasiah et al., 2018). Key milestones include the 1992 Rio Earth Summit that led to the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 and the annual Conference of the Parties (COP) meetings to monitor progress (Dormido et al., 2023; Rasiah et al., 2018), the 1997 Kyoto Protocol, and the Paris Agreement, which remain central to global climate governance. The Sustainable Development Goals (SDGs) have further integrated climate action into a broader development agenda, complemented by global initiatives such as Agenda 21, the Sendai Framework, and the Addis Ababa Action Agenda (Morton et al., 2019).

Cities have emerged as key actors in addressing climate challenges, largely due to the voluntary nature of national commitments under the Paris Agreement. The latter has shifted responsibility from reluctant national governments to local authorities, positioning them as leaders in providing structured climate responses (Hofstad et al., 2023). The European Union (EU), a global leader in climate policy, has reinforced this trend by setting ambitious targets through the 2019 European Green Deal (Dormido et al., 2023). The EU has positioned cities at the forefront of implementing its green agenda—most notably through its initiative to achieve 100 climate-neutral and smart cities by 2030 (European Commission, 2021). This is unsurprising, given that cities both contribute to and are directly affected by climate change. As such, they must secure an appropriate institutional infrastructure and take concrete action towards decarbonisation and adaptation to changing climatic conditions (Hofstad et al., 2022).

In this context, cities have often resorted to co-creation as the most suitable approach for addressing climate change and achieving carbon neutrality (Lund, 2018; Van Dis et al., 2023). While not all complex public problems are inherently "wicked" and may still be addressed through traditional policymaking approaches, scholars (e.g., Sørensen & Torfing, 2022) widely agree that climate change qualifies as a wicked problem due to its lack of clear-cut causes, predefined solutions, and the conflicting social and political interests shaping potential solutions. Co-creation emerges as the only way forward, as no single actor possesses the resources, knowledge, and skills required to comprehensively address climate challenges. Instead, climate change requires innovative solutions emerging from collaborative actions and synergies among elected politicians, public managers, researchers, businesses, civil society organisations, and citizens.

While co-creation has been integral to cities' strategies to address climate change, it has not been accompanied by a vibrant and critical academic discussion about mitigating the consequences of climate change (Sørensen & Torfing, 2022). This gap has resulted in a lack of research on the topic and a deficiency of tools for assessing and reflecting on co-creation efforts within this policy area. While some methodologies and guidelines in this specific context exist, they do not directly address the quality of co-creation processes. For instance, Hunter et al. (2022) relied on Blackstock et al.'s (2007) methodology for assessing the sustainability of participatory actions to evaluate co-creation efforts at a climate change academic conference aimed at bridging science and practice. Hofstad et al. (2022) examined the implementation of three ideal co-creation strategies—the "whole of government strategy"; the "externally focused stakeholder strategy"; and the "externally focused civil society strategy"—finding the latter to be the least developed at the city level.

Since leadership practices and effective institutional design are recognised as key factors for effective co-creation strategies in climate governance (Sørensen & Torfing, 2022), a list of leadership tasks has been identified as preconditions for successful co-creation (Hofstad et al., 2023). While this list may serve as a checklist for evaluating specific co-creation initiatives, it is limited to the actions of leadership and does not encompass the entire co-creation process. In contrast, the Life Cycle Co-Creation Process of nature-based solutions for urban climate change adaptation (DeLosRíos-White et al., 2020) specifically focuses on the co-creation process by defining five stages—CoExplore, CoDesign, CoExperiment, CoImplement, and CoManagement—and offering tools for stakeholder engagement in each stage. However, while valuable for guiding implementation, this framework is not suitable for ex-post evaluations.

Unlike other policy areas where specific frameworks for the evaluation of co-creation initiatives exist—such as energy (Sillak et al., 2021) and health (Harris et al., 2019)—no evaluation instrument has been developed for assessing climate change-related co-creation in urban settings. This raises an important question: Do we need a specific, policy area-bound instrument for evaluating the quality of co-creation? Given the significant overlap of co-creation drivers and barriers across policy areas (Vrbek & Pluchinotta, 2021), we assume that a specialised tool is not needed. Instead, this article presents a universal decision support model (DSM) for assessing the quality of co-creation initiatives, developed within the context of the COGOV Horizon project. Because the model is not tailored to a specific policy area, our goal is to critically examine and test its relevance in the context of climate change-related co-creation initiatives in urban settings, using the case of the Bee Path co-creation initiative launched by the City of Ljubljana. Thus, we also aim to critically revisit the initial assumption that a universal model will suffice for this purpose.

To achieve this, our research was guided by the following research questions:

> RQ1: What are the drivers and barriers that affect the quality of co-creation?
>
> RQ2: How can this knowledge be used to design a multi-criteria DSM for assessing the quality of the co-creation process?
>
> RQ3: Is such a universal model suitable for assessing co-creation processes, specifically in the context of climate change policy at the city level?

The primary objective and originality of this article lie in its effort to bridge theory and practice by translating existing knowledge on co-creation drivers and barriers into a practical tool aimed at supporting public organisations in becoming more effective co-creators. To achieve this objective and answer the research questions, the article is structured as follows. The next section provides a theoretical discussion of the concept of co-creation, followed by an overview of the research methodology in Section 3. Section 4 outlines the multi-criteria DSM for assessing the quality of co-creation, detailing its criteria, structure, and operationalisation for end users. Section 5 presents the results of applying the model to the Bee Path project in the City of Ljubljana. Finally, Section 6 answers the research questions, discusses the study's contribution to the literature on co-creation, and offers suggestions for future research.

2. Co-Creation: A Theoretical Perspective

In the aftermath of the 2008 economic crisis, the failure of top-down approaches to mitigate the crisis's effects exacerbated public sector challenges, undermined citizens' well-being (Selloni, 2017), and deepened the democratic deficit (Giannone, 2015). This led to a paradigmatic shift in how public administrations perceive their roles and citizens' expectations. On one hand, public administrations encountered austerity and new crises; on the other, they faced growing demands for high-quality public services (Steen et al., 2019). Consequently, the conventional approaches of traditional public administration (TPA) and new public management (NPM) were deemed insufficient to address contemporary challenges (Torfing & Triantafillou, 2013).

The shift to new public governance (NPG; Osborne, 2010) has pushed public administrations towards becoming "arenas of co-creation" (Torfing et al., 2019), promoting collaboration among relevant and affected public and private actors to address complex, wicked problems (Torfing, 2019). This shift challenges TPA assumptions, requiring new forms of power-sharing and partnerships based on equality (Ansell & Torfing, 2021). However, this transition is not straightforward, as TPA, NPM, and NPG often coexist in practice, with the dominant approach varying by context. While co-creation aligns with NPG, successful initiatives have also been observed within TPA- and NPM-driven settings (Van Gestel et al., 2023).

Despite its growing appeal as a "magic concept" (Torfing, Sørensen, & Breimo, 2023), co-creation suffers from conceptual stretching and ambiguity, particularly in distinguishing it from related concepts like co-production, co-design, and co-governance (Jukić et al., 2019). While often used interchangeably, co-creation and co-production differ fundamentally. Co-production focuses on service-level involvement (Ostrom, 1996; Steen et al., 2019), whereas co-creation is broader. W. H. Voorberg et al. (2015, p. 1348) differentiate them based on the role of citizens: In co-production, citizens are involved in service implementation, while in co-creation, they are equally involved in co-initiation or co-design. Torfing et al. (2019, p. 802) provide a framework for distinguishing the two by participants, public value creation, and innovation. Co-production involves collaboration between service providers and users for service delivery and incremental improvements, whereas co-creation brings together diverse participants to pursue transformative innovation. Hence, Torfing et al. (2019, p. 802) define co-creation as follows:

> A process through which two or more public and private actors attempt to solve a shared problem, challenge, or task through a constructive exchange of different kinds of knowledge, resources, competences, and ideas that enhance the production of public value in terms of visions, plans, policies, strategies, regulatory frameworks, or services, either through a continuous improvement of outputs or outcomes or through innovative step-changes that transform the understanding of the problem or task at hand and lead to new ways of solving it.

Co-creation is praised for its ability to mobilise diverse societal resources to generate public value and tackle complex, wicked problems beyond the reach of traditional policy tools (Cluley & Radnor, 2021; Livingstone, 2023; Touati & Maillet, 2018). At the service level, it promotes more efficient, user-centric services of higher quality and lower cost, enhancing user satisfaction (Bovaird et al., 2015; Osborne et al., 2016; W. H. Voorberg et al., 2015). Beyond services, co-creation fosters social cohesion, active citizenship, democratic legitimacy, and stronger ownership (Bryson et al., 2002; Caitana & Moniz, 2024; Fledderus et al., 2014; Indra et al., 2024; Osborne et al., 2016; Touati & Maillet, 2018; W. H. Voorberg et al., 2015).

However, co-creation also carries risks. If misapplied or manipulated, it can undermine public value (Virtanen & Jalonen, 2024) and produce biased solutions that favour privileged groups while marginalising others (Edelmann & Virkar, 2023; Torfing et al., 2019). Instead of enhancing legitimacy, it can erode it by shifting policy responsibilities onto citizens, blurring accountability (Virtanen & Jalonen, 2024). Moreover, it can increase complexity and costs, requiring additional planning, management, and supervision. In Central and Eastern Europe (CEE), these risks are heightened due to interest group influence, stakeholder polarisation, and public sector reluctance (Indra et al., 2024; Vrbek & Kuiper, 2022). A key challenge across all contexts is tokenistic participation, where co-creation is used as a substitute rather than a complement to representative democracy (Cilliers et al., 2024).

These challenges highlight the need for a selective application of co-creation, which is not a one-size-fits-all solution and should not be used indiscriminately (Torfing, Sørensen, & Dečman, 2023). When effective policy solutions already exist, co-creation should not be pursued for its own sake (Hofstad et al., 2023). However, public organisations often struggle to determine when co-creation is the most suitable approach (Vrbek & Jukić, 2024). In addressing complex issues like climate change, the need for co-creation becomes more evident. As a quintessential wicked problem, climate change requires inclusive, innovative solutions due to its global scale, cross-sectoral impact, and unequal consequences (Sørensen et al., 2021). Urban residents, who are disproportionately affected (Fox et al., 2022), must be engaged as equal partners in shaping urban spaces. Some scholars, like Clavin et al. (2021), call for a more critical approach to co-creation in environmental policy, acknowledging conflicts and injustices rather than solely seeking consensus. Others, like Carpenter and Horvath (2022), advocate integrating art into urban planning to foster more creative and emotionally-engaging approaches.

Even when public organisations identify appropriate co-creation opportunities, significant challenges persist. Many lack the infrastructure and expertise needed for effective implementation while facing external pressures from international bodies (e.g., the OECD and the EU) and internal demands for collaborative innovations (Torfing, Sørensen, & Breimo, 2023). However, enthusiasm and implementation alone rarely ensure success—the quality of co-creation largely depends on the capacity of public servants to support the process (Engen et al., 2021; Magnussen & Rønning, 2021). To address capacity-related limitations in co-creation, Caitana and Moniz (2024) propose management tools to shift the mindset of urban planning actors in public institutions. Steen et al. (2019) highlight the need for researchers to engage with practice as partners rather than mere subjects of study. The goal of these efforts is to extend co-creation beyond isolated projects (Van Gestel et al., 2023) and integrate it as a standard policymaking approach.

Assuming that key decisions on the adoption and organisation of co-creation as a problem-solving approach typically rest with public organisations, this article examines the development of a tool to assess co-creation quality. Designed for public servants responsible for organising and coordinating the co-creation process, this tool provides a framework for critical reflection on their actions to achieve effective co-creation. Ultimately, it seeks to enable public organisations to derive valuable lessons and identify strategies to enhance their capacity as co-creators in future initiatives.

3. Methodological Framework

This article presents a model for assessing the quality of co-creation processes developed between 2019 and 2022 within the framework of the COGOV Horizon project and critically discusses its applicability in addressing climate challenges in urban environments. For this purpose, in 2024, the model was tested in a real-life situation—the Bee Path project of the City of Ljubljana.

This multi-criteria DSM relies on three key methodological pillars (see Figure 1):

- Content analysis of Web of Science (WoS) papers referring to co-creation;
- Seven case studies (vignettes) of promising organisations practising co-creation;
- Multi-criteria decision analysis (MCDA).

The first two methods provided empirical insights that shaped the content of the model, precisely the model attributes referring to specific aspects of co-creation necessary for ensuring process quality. The third method established the hierarchical structure within which these evidence-based findings were organised and operationalised for end users.

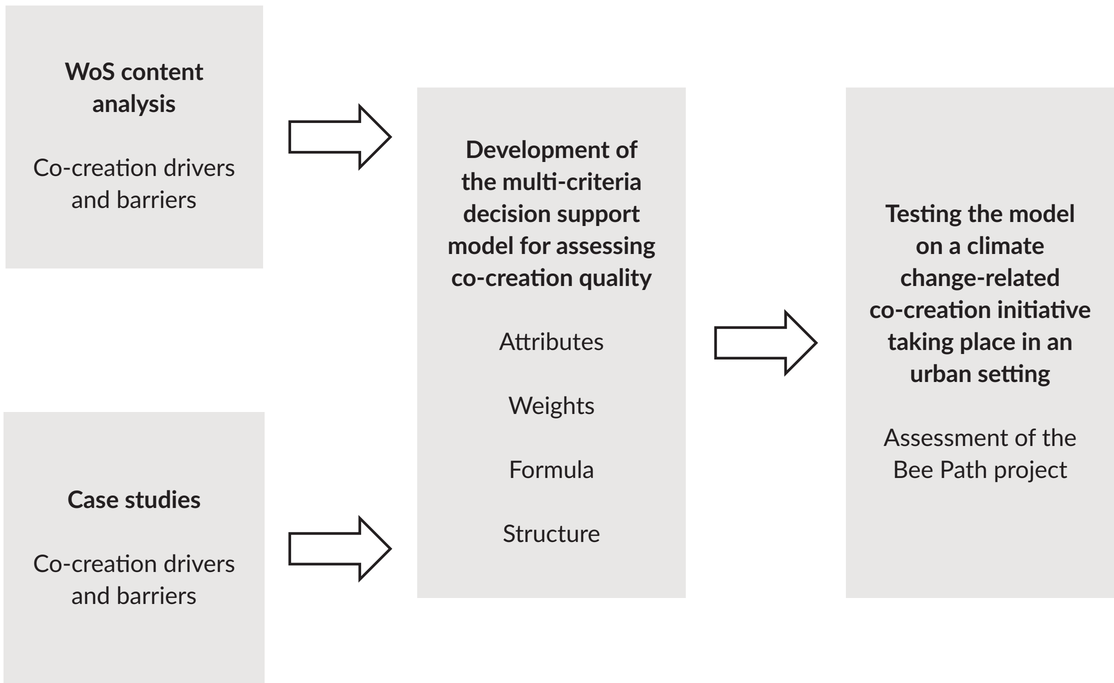


Figure 1. Methodological framework of the model development.

3.1. Systematic Literature Review

The systematic literature review was one of the methods used to define the substance of the model, specifically by identifying co-creation drivers and barriers, which served as the basis for the definition of the model attributes. We analysed 139 WoS papers, selected based on the following criteria:

- 10-year timespan (2009–2018);
- Keywords: "co-creation" or "co-production";
- Type: Article;
- WoS category: Public Administration;
- Language: English.

The search strategy was deliberately narrow, focusing only on the keywords "co-creation" and "co-production," which are often used interchangeably. While related concepts like "collaborative governance" may offer relevant insights, our aim was to maintain conceptual clarity and avoid further conceptual stretching. This strategy yielded 155 scientific papers, providing a robust and relevant dataset for systematic analysis (see Figure 2), even without additional keywords. Following the data cleaning process (Figure 2), we identified co-creation drivers and barriers in 109 articles, which were then further analysed. More detailed information about the methodological aspects and conclusions of the systematic literature review can be found in COGOV Deliverables 7.1 and 7.3 (Jukić, Hržica, et al., 2022; Vrbek et al., 2022).

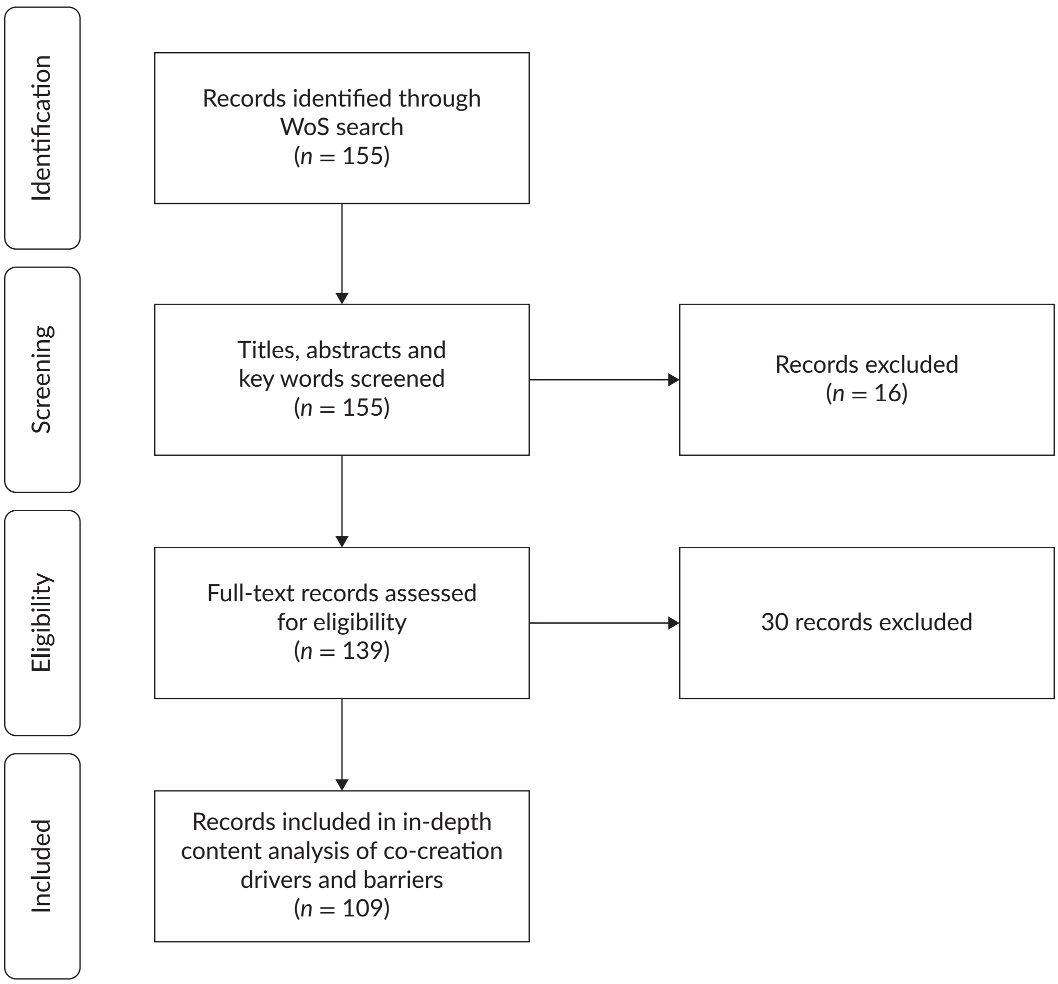


Figure 2. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram illustrating the steps of identifying relevant literature for further content analysis.

3.2. Case Studies

We validated and supplemented the findings of the systematic content analysis with co-creation drivers and barriers identified in seven case studies (see Table 1) conducted across six countries as part of Work Package 4 (WP4) of the COGOV project, specifically Task 2.1 (Torfing & Sørensen, 2022). The primary objective of WP4 was to conduct design experiments—beyond the scope of this article—by inviting project partners to nominate suitable cases at both local and central levels. Case selection followed key criteria shared across all participating organisations:

- Integration of co-creation principles into organisational strategies or vision;
- Availability of platforms (digital or physical) supporting co-creation efforts;
- Capacity for critical reflection on co-creation drivers and barriers based on experience.

The selected cases included public organisations at various governance levels and, crucially, with different levels of experience and maturity in co-creation—two in early stages, three in progress, and two relatively advanced (Torfing & Sørensen, 2022). This approach ensured that potential barriers were not overlooked due to differences in organisational maturity.

For the development of the model, we relied on internal case study reports that captured the experience of the seven public organisations. Additionally, for five of these case studies, we obtained supplementary information on specific co-creation experiences/initiatives undertaken by the organisations. These insights expanded and reinforced the list of attributes identified through the systematic literature review.

Table 1. Case studies.

Country	Project partner/Authors	Case study (Task 2.1 WP4)
France	Aix-Marseille University team	Vitrolles Municipality case
Croatia	City of Rijeka team	City of Rijeka case
UK	Cardiff University (authors: Martin Kitchener and Kim Dearing)	Torfaen County Borough Council's A Good Day initiative
UK	Northumbria University team	Newcastle City Council and Co-creation
The Netherlands	TIAS School for Business and Society (authors: Sanne Grotenbreg and Nicolette Van Gestel)	Strategic efforts of the Social Service Department of Drechtsteden to spur co-creation
Denmark	Roskilde University team	Gentofte Municipality case
Slovenia	University of Ljubljana (author: Mitja Dečman)	Ministry of Public Administration case

3.3. Multiple Criteria Decision Model

Traditional decision-making often focuses on a single objective, which may overlook the complexity of a problem. In contrast, MCDA considers multiple factors simultaneously, offering both structured solutions and a deeper understanding of the problem, preferences, and alternatives (Doumpos et al., 2019). Its primary advantage lies in breaking down complex decisions into smaller, manageable parts, enabling easier analysis and integration into a comprehensive solution (Svoboda & Lande, 2024). This method forms the foundation of our model, which consists of the following:

- Attributes (or criteria) representing the various dimensions of a successful co-creation process. Each attribute is linked to a factor that either supports or hinders co-creation. They were defined based on co-creation drivers and barriers identified in WP4 and an analysis of research papers from WoS.
- Each attribute has a range of possible values. In the model, these values are shown as "yes/no" answers to corresponding questions, which operationalise the DSM attributes.

- Attribute weights indicate the degree of their impact on the final score. Although DSMs typically presume a hierarchy of attributes, our model is simpler, consisting of attributes without preassigned weights. Instead, all model attributes are equally weighted and assessed directly by users.
- The formula provides the basis for quantifying the quality of a co-creation process.

3.4. Testing Site: The Bee Path Project

The decision to test the model on a co-creation initiative addressing climate challenges in the City of Ljubljana was based on several key considerations. The Slovenian administrative context mirrors that of the broader CEE region—a largely underexplored area in co-creation research (Vrbek & Kuiper, 2022). This selection helps counterbalance potential contextual biases of the existing literature, drawing predominantly on experiences from Western and Northern Europe (Jukić et al., 2019). Given the CEE region's inclination toward TPA, examining co-creation in this setting may reveal distinct factors that extend beyond well-documented general drivers and barriers (Indra et al., 2024).

The City of Ljubljana serves as an ideal case study for two reasons. First, it exemplifies a typical TPA administrative setting where co-creation has been successfully applied and structurally supported (Regal et al., 2024). Second, it prioritises the green agenda, earning the title of Europe's Green Capital in 2016. This combination offers a suitable environment for testing the co-creation tool in environmental policy, with potential insights applicable to the broader CEE region.

The Bee Path project was selected as the test initiative based on its following characteristics:

- Proven success in co-creation;
- Ongoing sustainability;
- Focus on climate change within an urban environment.

Recognizing the critical role of pollinators in urban ecosystems, the City of Ljubljana launched the Bee Path project in 2015 (URBACT, 2017). The initiative aimed to foster a bee-friendly urban environment and promote self-sufficiency through innovative co-creation activities. The project is notable for its comprehensive approach to raising ecological awareness and promoting urban sustainability by including the following (Strmšnik et al., 2022):

- A physical path connecting significant urban beekeeping sites;
- A network facilitating collaboration among stakeholders;
- An educational program to raise awareness and spread knowledge about urban beekeeping;
- An incubator for developing new products and services related to urban beekeeping;
- A movement engaging citizens and stakeholders in promoting high environmental awareness.

In 2017, the initiative earned the URBACT program award for good practice, underscoring its innovative approach. Following this recognition, the Bee Path project not only expanded its impact within Ljubljana (through new partnerships and enriched content) and other Slovenian cities (e.g., Maribor), but also served as a model to be replicated in other European cities (IPoP, 2021). This led to the formation of the Bee Path Cities network, the successor to the previous two URBACT networks, BeePathNet and BeePathNet Reloaded, operating from 2018 to 2022 (URBACT, 2024).

To understand the meaning and impact of co-creation in this case, we employed two data-gathering methods: qualitative analysis of project documentation, and a semi-structured interview with the Bee Path project coordinator Maruška Markovič (personal communication, 5 March 2024).

4. A Multi-Criteria DSM for the Assessment of the Quality of Co-Creation

4.1. Model Criteria

Based on the systematic literature review and case studies, we identified 19 attributes for the model. Due to their relatively high number and clear reference to a specific phase of the co-creation process, we grouped them into three categories (for more information see Vrbek et al., 2022):

- Identification and mobilisation of stakeholders: referring to the preparation phase before co-creation takes place;
- The co-creation process: capturing the act of co-creation itself;
- Effects of co-creation: referring to the post-co-creation phase.

This categorisation provides a logical framework and thus a clearer flow of thought for end users of the model while assessing the quality of specific co-creation initiatives. In the following subsections, we present the attributes within each category (Vrbek et al., 2022).

4.1.1. Attributes Referring to the Identification and Mobilisation of Stakeholders

4.1.1.1. Identification and Inclusion of all Affected and Relevant Stakeholders

For successful co-creation, it is crucial that a public organisation initially identifies all affected and relevant stakeholders (Bryson et al., 2002; Dečman, 2020; Grotenbreg & Van Gestel, 2020; Newcastle Team, 2020; Rijeka Team, 2020). This involves reaching out to both those who have an interest in solving a problem and those who have the power and authority to design, finance, implement, and consolidate the solution. The former implies, inter alia, the inclusion of "seldom heard" vulnerable groups (Aix Marseille Team, 2020; Pill & Bailey, 2012), which is crucial for ensuring diversity among stakeholders affected by the problem (Griffiths, 2015). Hence, for the successful fulfilment of this attribute, some authors (Bryson et al., 2002) suggest conducting a thorough stakeholder analysis at the onset of the co-creation process.

4.1.1.2. Information About the Process

Stakeholders must be publicly and clearly informed about the opportunity to participate in the co-creation process (Griffiths, 2015). For wider and more effective dissemination of this information—reaching different groups of stakeholders—public organisations should use various communication channels, including social and traditional media (Ostling, 2017).

4.1.1.3. Communication of Potential Benefits

Public organisations need to clearly communicate the potential benefits of the co-creation process for external stakeholders (Gebauer et al., 2014). This can be achieved by referencing previous successful experiences of co-creation, i.e., by setting an example and thus inspiring participation in the present case of co-creation (Aix Marseille Team, 2020).

4.1.2. Attributes Referring to the Co-Creation Process Itself

4.1.2.1. Appointed Team Embedding the Idea of Horizontal, Distributive, and Integrative Leadership

Public organisations need to appoint a team responsible for the conduct of the co-creation process (Aix Marseille Team, 2020; Kitchener & Dearing, 2020; Rijeka Team, 2020). This team should be capable of managing the process, motivating stakeholders (and preventing opt-outs), and reconciling different views (Dečman, 2020). This presupposes a distributive, horizontal, and integrative leadership that facilitates collaboration and the involvement of staff (at all levels) in self-regulating teams, as well as inter-organisational and cross-sectorial interaction (Sørensen & Torfing, 2016, p. 132).

4.1.2.2. Clear Definition of Appropriate Roles

It is crucial that the roles and responsibilities of all participants in the process are clearly defined (Blume, 2016; Kekez, 2018; Newcastle Team, 2020; Steele, 2016; Williams, LePere-Schloop, et al., 2016). Their roles should be assigned in a way that enables them to contribute most effectively to the process (Rijeka Team, 2020). Specifically in public organisations, three key roles are particularly relevant for the success of the process:

- The sponsor: a higher-level figure who is less involved but provides authority, funding, or connections to move the change effort forward (Crosby & Bryson, 2010);
- The champion: a staff member who manages and organises the process on a daily basis (Crosby & Bryson, 2010);
- The facilitator: a person responsible for reconciling different needs and desires with the purpose of reaching a mutual agreement (Duijn et al., 2010; Howell & Wilkinson, 2016; Jones et al., 2016; Kane & Boulle, 2018; Mikusova Merickova et al., 2015; Oldfield, 2016; Rose, 2016; Sicilia et al., 2016).

4.1.2.3. Inclusion of External Stakeholders at an Early Stage

External stakeholders should be included at the beginning when the need for change is detected (Aix Marseille Team, 2020; Griffiths, 2015; McCabe, 2016), rather than at the end when a solution has already been defined and implemented—e.g., during the testing phase (Dečman, 2020).

4.1.2.4. Clear Explanation of the Framework

The framework within which the co-creation process takes place must be clearly explained to all participants (Williams, Kang, et al., 2016).

4.1.2.5. Channels of Communication

Digital technologies can be important tools for facilitating and enhancing co-creation with external stakeholders (Griffiths, 2015; Novani, 2016; Rijeka Team, 2020). However, while useful, digital tools have limitations (Newcastle Team, 2020); therefore, it is advisable that in some cases they are complemented by face-to-face communication (Kitchener & Dearing, 2020; Newcastle Team, 2020; Pestoff, 2014). Combining traditional channels of communication with digital ones could be beneficial for better inclusion and contribution of stakeholders who are less familiar with the latter (Ostling, 2017).

4.1.2.6. Equal Access

The relationship among co-creators should be based on equality (Andersen et al., 2017; Burall & Hughes, 2016; Cho et al., 2016; Kane & Boulle, 2018; Lindsay et al., 2018b; Saha, 2012; Sicilia et al., 2016; Tu, 2016; Wiid & Mora-Avila, 2018). This means that all external stakeholders must be given a voice and an opportunity to be heard (Dečman, 2020). However, achieving equality is challenging, as participants often possess different levels of knowledge, skills, expertise, information, and power (Burall & Hughes, 2016; Hardyman et al., 2015; Pestoff, 2014; Wiewiora et al., 2016; Williams, Kang, et al., 2016). Therefore, public organisations must ensure that participants are supported—that they receive guidance and help when needed (Breit & Salomon, 2015).

4.1.2.7. Clear and Common Goal

The expectations and goals of the process must be clear to all participants (Fledderus et al., 2014). Thus, all co-creators need to be committed to working collaboratively towards a common goal—from the design to the implementation of the solution (Dečman, 2020; Durose & Richardson, 2016; Lam & Wang, 2014; Ostling, 2017; Rijeka Team, 2020). Simply, this means achieving a shared understanding of the goal of the process, so that all participants walk in the same direction (Tu, 2016). Moreover, endorsement of this common goal by a public entity's board (if applicable), or a clear reference to the objectives and activities delineated in the organisation's strategic documents, provides additional leverage to the process (Ferlie & Ongaro, 2015, Chapters 2 and 3).

4.1.2.8. Reconciliation of Different Views

The team leading the co-creation process should ensure that the different needs and desires of participants are successfully reconciled (Aix Marseille Team, 2020; Duijn et al., 2010; Howell & Wilkinson, 2016; Jones et al., 2016; Kane & Boulle, 2018; Mikusova Merickova et al., 2015; Oldfield, 2016; Rose, 2016; Sicilia et al., 2016). This, however, should not come at the price of silencing certain views at the expense of others—rather, it needs to be achieved through a compromise that will lead to a solution acceptable to all participants in the process.

4.1.2.9. Meaningful Data

The availability of meaningful data (Rutherfoord & Spurling, 2016) and the sharing of this information with participants are crucial for successful co-creation (Newcastle Team, 2020). Although this might represent a challenge when dealing with sensitive issues (Newcastle Team, 2020), it is important that any obstacles preventing data sharing among participants are duly overcome.

4.1.2.10. Easy and Clear Tasks

The tasks within the co-creation process should be simple and clearly divided among participants, targeting small successive changes (Aix Marseille Team, 2020; Alford & Yates, 2016; Fledderus et al., 2014). Also, they need to be meaningful and explicitly connected to larger change efforts, providing salience to those investing their time and effort (Isett & Miranda, 2015).

4.1.2.11. Sufficient Time

It is crucial that participants have sufficient time for deliberation and performance of their tasks (Burall & Hughes, 2016; Isett & Miranda, 2015). Participants need to stay up-to-date with various elements of the process (Kane & Boulle, 2018). This implies that each person's timeframe and limits are respected (Aix Marseille Team, 2020) and participants do not feel pressured to neglect their regular work because of the co-creation process (Newcastle Team, 2020).

4.1.2.12. Shared Ownership

Participants need to share ownership and responsibility for the results of the co-creation process that will be implemented in practice (Burall & Hughes, 2016; Durose & Richardson, 2016; Gebauer et al., 2014; Nemec et al., 2019; Roskilde Team, 2020).

4.1.3. Attributes Referring to the Effects of Co-Creation

4.1.3.1. Open-Mindedness

Co-creation requires self-aware, self-conscious, and open-minded participants able to step outside their own mental framework to make mutual readjustments based on their joint consideration of the problem (Burall & Hughes, 2016; Durose & Richardson, 2016; Kemp & Rotmans, 2009).

4.1.3.2. Change

Co-creation is successful when new understandings, insights, and ideas are developed, forming the basis of new solutions (Roskilde Team, 2020). The contribution of external stakeholders must be integrated into the design of the final solution (Dečman, 2020), often resulting in significant changes to existing institutional structures and processes (Williams, Kang, et al., 2016). Instead of supporting or legitimizing existing solutions (Lövbrand, 2011), co-creation should lead to unanticipated outcomes and new ways of working (Kitchener & Dearing, 2020).

4.1.3.3. Resources

Co-creation is an expensive process that requires human and financial resources for its implementation (Lövbrand, 2011; Rijeka Team, 2020; Roskilde Team, 2020). Therefore, public organisations should secure sufficient resources for the implementation of both the process itself and the result/solution agreed (Kitchener & Dearing, 2020; Lindsay et al., 2018a). Transparent use of resources is also crucial, as the process should not be discredited by suspicions or claims of alleged misuses (Williams, Kang, et al., 2016).

4.1.3.4. Clear Communication of Results

The input of external co-creators should be integrated into the final implemented solution (Rijeka Team, 2020). Hence, it is important that public organisations provide feedback on how external contributions were considered (Williams, Kang, et al., 2016). Participants need to see the impact of their involvement in the process (Newcastle Team, 2020). Therefore, public organisations must ensure that contributors understand their input was meaningful, even if their specific proposals were not (fully) included in the final solution (Griffiths, 2015).

4.2. The Structure of the DSM

After identifying the model attributes, we developed the DSM structure, which follows a hierarchical, tree-like format (see Figure 3) comprising two levels of attributes. The lower level includes 19 basic (i.e., subordinate) attributes, corresponding to those discussed earlier (Sections 4.1.1–4.1.3). These are grouped into three overarching parent attributes at the higher level, aligned with the three key categories—identification and mobilisation, the process, and effects (see Section 4.1). The hierarchical structure implies that each basic attribute directly influences its corresponding parent attribute (Bohanec, 2006, p. 104). Thus, any change in the value of a basic attribute automatically affects the associated parent attribute, thereby impacting the category's assessment score and the overall assessment of co-creation quality.

An example of a basic attribute is "Information about the process" (1.2). It is classified as basic because end users must enter a value for it—i.e., indicate whether participants were informed about the process. Based on the values provided by end users for all basic attributes, the model calculates the values for parent attributes at the first level. The corresponding parent attribute for our example is attribute 1, "Identification and mobilisation of stakeholders" (see Figure 3). Its value derives from the values of attributes 1.1, 1.2, and 1.3.

The highest attribute in the model represents the overall assessment of co-creation quality (top of Figure 3). It is derived from the values of all basic attributes, calculated using a formula that reflects the model's hierarchical structure (Vrbek et al., 2022):

$$\left(\left(\frac{\text{Number of answers implying "ready" (having value "1")}}{\text{3 (total number of attributes in category 1)}} \times \frac{\text{3 (total number of attributes in category 1)}}{\text{19 (total number of attributes or survey questions)}} \right) + \left(\frac{\text{Number of answers implying "ready" (having value "1")}}{\text{12 (total number of attributes in category 2)}} \times \frac{\text{12 (total number of attributes in category 2)}}{\text{19 (total number of attributes or survey questions)}} \right) + \left(\frac{\text{Number of answers implying "ready" (having value "1")}}{\text{4 (total number of attributes in category 3)}} \times \frac{\text{4 (total number of attributes in category 3)}}{\text{19 (total number of attributes or survey questions)}} \right) \right) \times 100 = \text{SCORE \%}$$

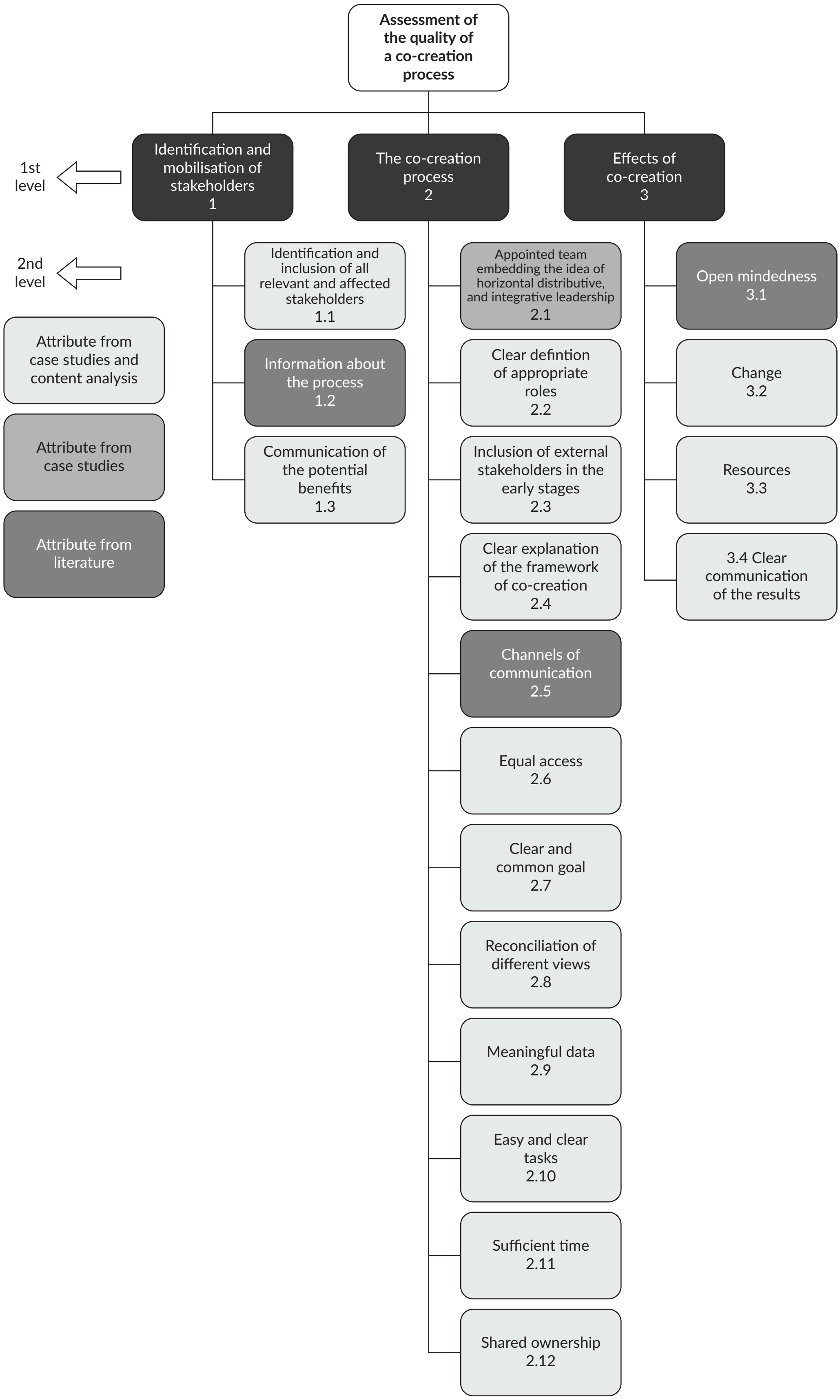


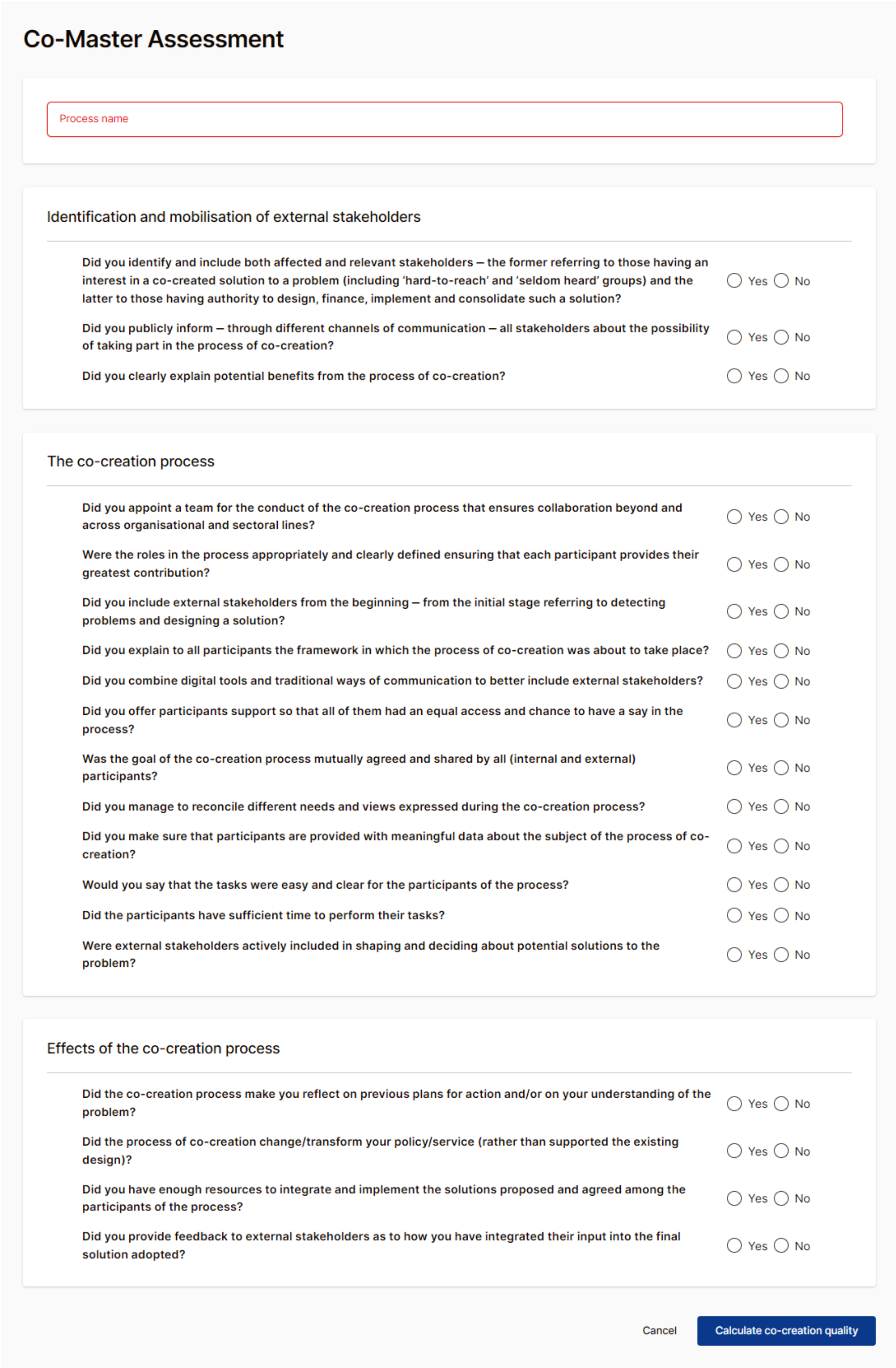
Figure 3. DSM for the assessment of the quality of co-creation processes. Source: Vrbek et al. (2022).

Our model is simplified by excluding preassigned weights, thus assuming equal importance for all attributes. This decision reflects the recognition that the impact of different attributes can vary significantly across national, policy sector, and governance contexts. By adopting this approach, we enhance the model's broader applicability, as it is impossible to establish universal weights applicable to all possible macro-, meso-, and micro-level contexts, intersecting with the specificities of policy areas and individual co-creation initiatives. Consequently, users are not constrained by predefined hierarchies of major or minor issues dictated by the model. Instead, the equal weighting approach ensures that all problematic aspects of their co-creation process are presented on an equal footing. This requires users to actively interpret the final score, which highlights identified challenges alongside recommendations for improvement, encouraging a critical assessment of their significance within their specific context (as demonstrated by the representative of the City of Ljubljana; see Section 5). Furthermore, by not assigning differential weights, the model remains highly adaptable and open to customisation, allowing users to define their own weights, whether at the organisational or policy sector level. This flexibility aligns with the core principles of DSMs, which are inherently modifiable, including users to adjust attributes and weights as needed. As such, this model serves as a foundational framework that can be further developed and refined based on the specific needs and objectives of public organisations.

4.3. Operationalisation of the Model for End Users

The model's internal structure and backstage processes remain invisible to end users, who interact therewith through a survey (see Figure 4). To assess the quality of the co-creation process, public servants coordinating it must answer all 19 survey questions, grouped into three sections corresponding to the model's attributes. Each question offers two response options: "Yes" (valued 1), indicating the condition for successful co-creation is met, and "No" (valued 0), indicating it is not. For attributes receiving a "No" response (valued 0), the model generates predefined textual interpretations, included in the final score to highlight areas where the organisation's performance is suboptimal.

To better illustrate the operationalisation of the model, we present a hypothetical assessment score from a user perspective (Figure 5). The textual explanation of the result is generated from the pre-prepared explanation of the "No" answers (valued 0), which in this particular case affect attributes 1.2 and 1.3 in the first phase of co-creation, "Identification and mobilisation of external stakeholders"; 2.3, 2.5, 2.8, 2.11, and 2.12 in the second phase, referring to the act of co-creation itself; and 3.1 and 3.2, undermining the effect of co-creation. With such a format, the model ensures a tailored and dynamic presentation of the score, depending on the values entered for the assessment of a specific co-creation initiative.



Co-Master Assessment

Process name

Identification and mobilisation of external stakeholders

- Did you identify and include both affected and relevant stakeholders — the former referring to those having an interest in a co-created solution to a problem (including 'hard-to-reach' and 'seldom heard' groups) and the latter to those having authority to design, finance, implement and consolidate such a solution? ◯ Yes ◯ No
- Did you publicly inform — through different channels of communication — all stakeholders about the possibility of taking part in the process of co-creation? ◯ Yes ◯ No
- Did you clearly explain potential benefits from the process of co-creation? ◯ Yes ◯ No

The co-creation process

- Did you appoint a team for the conduct of the co-creation process that ensures collaboration beyond and across organisational and sectoral lines? ◯ Yes ◯ No
- Were the roles in the process appropriately and clearly defined ensuring that each participant provides their greatest contribution? ◯ Yes ◯ No
- Did you include external stakeholders from the beginning — from the initial stage referring to detecting problems and designing a solution? ◯ Yes ◯ No
- Did you explain to all participants the framework in which the process of co-creation was about to take place? ◯ Yes ◯ No
- Did you combine digital tools and traditional ways of communication to better include external stakeholders? ◯ Yes ◯ No
- Did you offer participants support so that all of them had an equal access and chance to have a say in the process? ◯ Yes ◯ No
- Was the goal of the co-creation process mutually agreed and shared by all (internal and external) participants? ◯ Yes ◯ No
- Did you manage to reconcile different needs and views expressed during the co-creation process? ◯ Yes ◯ No
- Did you make sure that participants are provided with meaningful data about the subject of the process of co-creation? ◯ Yes ◯ No
- Would you say that the tasks were easy and clear for the participants of the process? ◯ Yes ◯ No
- Did the participants have sufficient time to perform their tasks? ◯ Yes ◯ No
- Were external stakeholders actively included in shaping and deciding about potential solutions to the problem? ◯ Yes ◯ No

Effects of the co-creation process

- Did the co-creation process make you reflect on previous plans for action and/or on your understanding of the problem? ◯ Yes ◯ No
- Did the process of co-creation change/transform your policy/service (rather than supported the existing design)? ◯ Yes ◯ No
- Did you have enough resources to integrate and implement the solutions proposed and agreed among the participants of the process? ◯ Yes ◯ No
- Did you provide feedback to external stakeholders as to how you have integrated their input into the final solution adopted? ◯ Yes ◯ No

Cancel | Calculate co-creation quality

Figure 4. The model's user interface. Source: Vrbek et al. (2022).

Your co-creation initiative 1 co-creation process was 53% successful

Keep in mind

Identification and mobilisation of external stakeholders

- Potential participants need to be publicly informed in a timely manner about the process of co-creation. The public organisation should ensure that the dissemination of this information takes place through various channels (inter alia social and traditional media), with the purpose of reaching as many different types of potential participants as possible.
- To mobilise and motivate participation, the public organisation needs to clearly communicate the potential benefits expected from the co-creation process. In this regard, it would also be helpful for the organisation to refer to previous successful co-creation experiences and 'advertise' their impact.

The co-creation process

- Digital technologies are considered to provide significant support for co-creation with external stakeholders. However, using traditional, i.e., face-to-face, communication in the process of co-creation is crucial when some of the stakeholders are not very skilled with digital tools. Therefore, the channels of communication and inclusion of external stakeholders should be selected and combined carefully, depending on the features of the target group(s).
- The team leading the process of co-creation should ensure that the participants' various needs and desires are successfully reconciled. This should not be done by silencing certain views at the expense of others, but by following the logic of the 'strongest argument' and 'consensus building'.
- It is crucial that participants have sufficient time for deliberation and performance of the tasks. Unreasonably short deadlines could cast doubts about the actual interest and intention of the public organisation to co-create.
- Participants need to share ownership regarding the solution to be implemented as a result of the co-creation process. This means that all participants need to be actively included in shaping and deciding upon the solution to the problem.
- External stakeholders should be included at the beginning of the process, at the stage of detecting problems and designing a solution. Including external stakeholders at the end, when a solution is already defined and implemented – for instance in the testing phase – could cast doubts about the actual interest of the public organisation to co-create.

Effects of the co-creation process

- A successful co-creation process makes participants step out of their mental framework and reflect on their understanding of the problem. The very purpose and quality of co-creation could be questioned in a case where participants have not learned anything new, have not changed their initial positions/plans or have the same understanding of the problem as before the start of the process.
- Co-creation should lead to change, i.e., to new ways of working, and the improvement of the present state of play. A result of the process that supports and legitimises existing solutions could raise questions about the very need/intention of co-creation, the design of the process, and/or the composition of participants.

Figure 5. Hypothetical assessment of co-creation quality. Source: Vrbek et al. (2022).

5. Testing of the Model

The model was tested on the Bee Path project of the City of Ljubljana, which achieved a 95% success rate in the co-creation process. For a structured discussion and better understanding of this result, we discuss the fulfilment of the model attributes within each of the three sections: identification and mobilisation of stakeholders; the co-creation process; and the effects of co-creation.

The assessment confirms that the City of Ljubljana successfully addressed the initial phase concerning the identification and mobilisation of stakeholders (attribute 1.1), despite initially taking a different approach. Namely, the project evolved naturally by gradually incorporating a broad spectrum of participants over time, rather than at the outset as suggested in the literature. As the city lacked a clear idea in the beginning, it engaged in dialogue with beekeepers' associations recognised as the most competent actors on the topic. This early collaboration quickly revealed new dimensions and opportunities for innovative experimentation, encouraging the inclusion of additional entities such as cultural and educational institutions (e.g., Cankarjev dom, Ethnographic Museum, Kino Šiška, Faculty of Architecture) and private actors (e.g., hotels, malls). The expansion of the collaboration made many of the new participants keen on taking an active part by modifying their spaces to enable urban beekeeping, which had a further ripple effect on the creation of innovative products such as protocol gifts featuring local honey, strategical planting of honey plants throughout the city, and the development of educational and tourism content linked to various urban beekeeping locations.

Initially, it was the municipality that proactively approached external stakeholders (attribute 1.2); however, as the initiative gained momentum and visibility, the dynamic shifted, with many external actors approaching the municipality, seeking involvement. This shift was supported by both formal and informal communication channels established by the municipality, including an online registration form. Moreover, the municipality clearly defined and communicated the benefits of the co-creation process, precisely those at the collective (societal) level (attribute 1.3). The potential individual benefits were intentionally disregarded, i.e., narrated explicitly by the municipality, leaving the interpretation entirely to (potential) partners. This approach was recognised as the only proper way of ensuring that participants had a genuine interest and desire to engage in the project, which is crucial for sustained motivation.

Moreover, the attributes referring to the second phase (i.e., the act of co-creation itself) were largely fulfilled, indicating a well-structured and well-facilitated initiative under the auspices of the City of Ljubljana. While allowing room for experimentation, the co-creation process maintained a certain structure, including designated city representatives (2.1) and a defined framework of established (meeting and decision-making) rules accepted by all participants (2.4). Nevertheless, the co-creation framework was not strictly detailed, enabling natural progress and future development—such as adopting a vision and action plan based on the collective input of all participants, which later established a clearer institutional infrastructure through various topical workgroups. Participants had clear roles (2.2) and tasks appropriate to their backgrounds and skills (2.10), as well as sufficient time to complete them (2.11). The external stakeholders, initially drawn from the beekeeping community, diversified over time, attracting a broader array of participants, even those unrelated to beekeeping as such (2.3). This expansion translated into a wider scope of the project, encompassing new areas like tourism and education, while maintaining the general goal of creating a bee-friendly, sustainable city (2.7). Moreover, co-creation activities took place through both traditional and digital channels (2.5), the latter playing a key role in sustaining the initiative during the Covid-19 pandemic. The role of the city coordinator was also pivotal for the quality of the co-creation process given their efforts in gathering and disseminating relevant data (2.9) and maintaining active, constructive collaboration among participants (2.8). According to the coordinator's assessments, in 90% of cases, conflicting interests and needs were successfully reconciled, leading to synergy and the joint development of specific innovative products (2.12).

According to the model, the project met all criteria in the second section concerning the act of co-creation itself, except for equal access (2.6). While the process was open and inclusive, its design lacked an institutionalised support mechanism to help participants overcome specific (both tacit and objective) challenges to achieve equal access and influence in the co-creation process. Instead, such mechanisms and activities were primarily designed and directed at end users of the co-created products—for example, by making tourism and educational programs accessible to the blind and those with physical disabilities. This raised concerns about not all stakeholders being equally equipped to voice their opinions in co-creation processes, prompting the need for the public organisation to ensure explicit instruments/protocols so that certain participants are not overshadowed by more dominant and vocal stakeholders. Specifically, the assessment score recommended additional efforts to help participants better express their needs and perspectives during the co-creation process. However, the interviewee convincingly argued that the absence of such a mechanism did not undermine the co-creation process because all co-creators had certain competitive strengths (resources), as well as a clear idea of their individual expectations and thus strong interest in participating, which facilitated their articulate and active participation in developing specific products and co-creating value.

Eventually, the Bee Path project met the model criteria for the final phase relating to the effects of co-creation. Namely, the City of Ljubljana maintained an "open mind," allowing cooperation among participants to evolve in unexpected directions (3.1 and 3.2). The project's results were not at any point of the initiative predefined by the city; rather, they emerged organically from the collaboration of various actors. External co-creators not only actively participated in the design, but the City of Ljubljana even stepped back, allowing them to implement the agreed solutions, which undoubtedly enhanced their sense of ownership. A notable strength of the project was the institutionalised resource allocation (3.3) by the City of Ljubljana (in addition to the voluntary contributions from the Bee Path members), ensuring that what was agreed was not a dead letter. Thus, the city annually invested between €17,000 and €27,000, which covered 20% of the costs for the coordinator's salary, meeting venues, and other project activities (Strmšnik et al., 2022). It is important to emphasise, however, that the city did not provide financial incentives to external co-creators to develop specific content/solutions, which aligns with literature findings that monetary incentives are less effective than a genuine interest in co-creation (W. Voorberg et al., 2018).

Finally, the project's visibility—achieved through its activities such as the Day of Bees and education and tourism programs—raised awareness among participants and the general public about the results and benefits of the initiative (3.4). The City of Ljubljana disseminated the outcomes through established (official) channels, including an annual meeting, where participants recapped and reflected on their work, and a newsletter. The project received international recognition in 2017 as a good practice example in an URBACT tender, which paved the way for scaling up its impact across several EU cities.

6. Discussion and Conclusion

Building on the rich knowledge about co-creation drivers and barriers found in the existing literature and empirical cases, we extracted the conditions that determine what constitutes a quality co-creation process, thereby answering the first research question (RQ1). By operationalizing the 19 criteria, the article contributes to a better understanding of the key aspects a co-creation process should encompass to provide a suitable framework to foster synergy, creativity, and innovativeness in addressing "wicked" problems.

In addition, by employing the multiple criteria decision-making methodology (Bohanec, 2006), the article answers the second research question (RQ2). This helped us structure the findings from the literature review and case studies into an applicative model that supports public organisations in critically reflecting on their co-creation experience, thus enabling them to become better co-creators. The model captures the process integrally, extending beyond the act of co-creation itself to its preparatory phase—specifically, the suitable approach to engaging relevant and affected stakeholders—as well as to its post-co-creation phase focusing on the sustainability of its outcomes and co-created value.

Given the model's ambition to be applicable across various contexts—such as different types of public organisations, national, and policy contexts, and particularly climate policy in urban settings—we refrained from assigning fixed, universal weights to the model's attributes. Instead of a black-and-white judgment, the model requires a more active role by its users in reflecting on and interpreting the scores (including the textual interpretation, i.e., the recommendations) through the prism of the specific case. The validity of our decision was further confirmed by testing the model on the Bee Path project. The shortcoming identified by our model in this case, regarding the potential threat to equal access, was not uncritically accepted as an actual threat to the co-creation process itself—mainly due to the profile of the stakeholders involved (see the previous section). Nevertheless, the model's recommendation on this matter still provided an important perspective for the City of Ljubljana, either for future co-creation initiatives or even for this project if it evolves to include less confident or marginalised participants.

Regarding RQ3 and the model's suitability for assessing co-creation processes in the context of climate change at the city level, the score calculated by the model closely reflected and articulated what the project coordinator intuitively felt about co-creation. A potential aspect requiring further attention is the (non)existence of mechanisms to motivate participants, especially those who become less active over time. This was identified as a key challenge for the City of Ljubljana, as maintaining the initial enthusiasm with the same intensity throughout the entire course of the process can be difficult, particularly when co-creation initiatives span long periods of time.

In terms of specific features of the climate change policy area that might pose a challenge to the applicability of the model, the "rigidity" of the goals and of the approach to tackling climate change set by national and local governments was pointed out. According to the interviewee, often when external stakeholders are invited to co-create, the general direction is already defined, and governments are not keen on deviating from their initial design, hoping that the process will only confirm their position. However, this specific problem was not present in the case of the Bee Path project, which remained open and lacked any predefined solutions throughout its development. The main reason for this was attributed to its "soft" content and approach to climate change, avoiding any major infrastructural interventions.

Although this was pointed out as a policy-specific problem, the model already covers this aspect (see attribute 3.1) by recognizing such rigidity as a general barrier to co-creation (found in any context). Thus, our research does not find the co-creation drivers and barriers in the case of the climate policy area to be different from the general body of factors that affect co-creation quality. As such, it aligns with existing research on barriers to climate change co-creation (e.g., Kumer et al., 2022), which find specific challenges to be bound only to individual cases rather than to the policy area of climate change as such.

Therefore, the answer to RQ3 is clear: The model is suitable for assessing co-creation quality in the context of climate change policies at the city level of governance. Moreover, the methodology used as the basis for its development, namely the multi-criteria decision method, enhances the flexibility and capacity of the model for further developments, countering any potential criticism regarding its suitability or the risk of becoming outdated. Specific aspects that have not been fully covered by the model can be easily added to its structure. This also allows users to further adapt the model to better reflect their specific situation by adding weights that apply to their context.

Thus, our article complements the co-creation literature and scholarly endeavours aimed at developing models for critical reflections on different aspects of co-creation efforts in the public sector. While existing models have dealt with organisational maturity for co-creation (Jukić, Pluchinotta, et al., 2022), co-creation readiness of public services (Vrbek & Jukić, 2024), outcomes of co-creation processes (Marsilio et al., 2021), and planning of co-creation processes (Davis & Andrew, 2017), our model provides an additional framework focusing specifically on the quality of the co-creation process per se. Hence, future research could explore possibilities for further upgrading such models, not only by expanding their substance (e.g., incorporating additional attributes) but also by integrating emerging technologies like AI. While hybrid approaches combining MCDA and AI have been widely explored in the private sector—e.g., in supplier selection (Abdulla & Baryannis, 2024), finance (Černevičienė & Kabašinskas, 2022), cybersecurity (Svoboda & Lande, 2024), and intermodal freight transportation (Tupayachi et al., 2024)—their use in the public sector remains limited due to ethical and legal concerns, stemming from the lack of explainability and transparency in AI-driven decision-making (Abdulla & Baryannis, 2024; Černevičienė & Kabašinskas, 2022). These challenges can be overcome if MCDA techniques remain at the core of the decision-making process, while machine learning is used to streamline analysis, e.g., by reducing the number of criteria or alternative scenarios. However, current research often prioritises AI over MCDA, either by relegating MCDA to a secondary role—despite its stronger foundation in explainable decision-making—or by failing to produce organic hybrids that fully exploit the strengths of both methods (Abdulla & Baryannis, 2024). In our model, integrating emerging technologies could facilitate broader input from co-creation ecosystem actors and enable the analysis of large volumes of social media content to inform co-creation assessment. Such an upgrade could also refine tailored recommendations for improving future co-creation initiatives by referencing and continuously updating best practices related to specific aspects (attributes) of the process.

Beyond the lack of integration of emerging technologies, the model has a few additional limitations. As with all self-evaluation tools, there is a risk of biased or socially desirable responses. However, the model operates on the assumption that it will primarily be used by organisations genuinely committed to improving their co-creation capabilities. Organisations lacking such ambitions or objective incentives are unlikely to invest the effort needed to manipulate the tool for favourable results, making this concern relatively low-risk. Another limitation is that the tool is designed specifically for public organisations, focusing on public servants as effective co-creators. Since co-creation involves a broader range of internal and external actors, additional tools, potentially integrating AI (as discussed above), could be developed to support collaborative assessments, fostering sustainable co-creation ecosystems beyond individual initiatives. Finally, the study's scope is limited, as the model was tested within a single organisation in one co-creation initiative. To improve generalisability and applicability, we encourage practitioners and policymakers to test and adapt the DSM to their specific contexts. The model's flexibility allows for such customisation, supporting informed decision-making across diverse settings.

Acknowledgments

We acknowledge the authors of the WP4 reports and appreciate the willingness of the Bee Path project coordinator Maruška Markovič to test the model.

Funding

This research was funded by the EU Horizon 2020 programme (Grant No. 770591) and the Slovenian Research and Innovation Agency (Grant No. P5-0093).

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The data used in this article, referring to the drivers and barriers extracted from the systematic literature review and the case studies, are available in Vrbek et al. (2022).

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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Urban Planning
2025 • Volume 10 • Article 9553
https://doi.org/10.17645/up.9553

ARTICLE

Open Access Journal

Adaptive Design Evaluator: A Co-Assessment Tool for Early Planning Stages

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Submitted: 31 October 2024 **Accepted:** 1 April 2025 **Published:** 4 June 2025

Issue: This article is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

Many municipalities face intense development pressures, challenging them to ensure spatial sustainability. Current assessment methods are designed for larger projects and are often time-consuming and resource intensive. Certification systems like ÖGNI, DGNB, LEED, and BREEAM use detailed but rigid criteria, making them unsuitable for dynamic co-creation processes. Smaller projects lack tools to visualize development impacts or generate tailored sustainability checklists. This article introduces the Adaptive Design (AD) Evaluator, an innovative, step-by-step methodology for sustainable impact assessment in building and planning projects. The AD Evaluator involves public and private stakeholders in a co-creation process, integrating questionnaires, system dynamics models and spatial analysis to efficiently assess project interventions. The results are presented visually, enabling adaptable, resource-efficient planning across four sustainability pillars. This approach supports quick assessments, offering perspectives from both developers and system owners (e.g., municipalities) and minimizes deviations from sustainable outcomes. The innovation of this approach lies in the introduction of the first conceptual scenario assessment generator for qualitative sustainability inventory and impact assessment in planning practice. The AD Evaluator supports the co-design of structured yet flexible planning pathways for sustainable and adaptive urban environments by mapping and visualizing the impacts of planning in a jointly negotiated framework.

Keywords

adaptive design; co-creation process; impact assessment; spatial life cycle; spatial sustainability; sustainable transformation

1. Introduction

Many municipalities face intense development pressures, which involve dealing with challenges based on social and technical needs and with limited financial capacities. In addition, they have to comply with overarching sustainability goals (e.g., sustainable development goals [SDGs], spatial planning concepts). Dealing with these challenges and thereby focusing on robust decisions for sustainable building developments demands expert knowledge.

The SDGs have also led to the accelerated development of certification systems and standards for circular economy and sustainable developments in the construction and planning sector, which "prove" the sustainability of building developments. Certification systems promise support in the creation of sustainable developments and, in addition to PR/marketing, are increasingly being used to assess the eligibility of sustainable developments for funding. These certification systems as well as currently available pre-assessments are able to evaluate actual projects based on detailed plans and designs and purport to offer planning and decision support.

In practice, however, decision makers often deal with different planning alternatives, not yet specified in detail. There are a multitude of different assessment systems that are rarely cross-sectoral. The assessments based on certifications are linked to external audits during the assessment process and do not focus on the involvement of decision makers or project developers. These external audits are time and cost-intensive processes and thus more likely to be considered for large projects. Life cycle assessments (LCAs) are standardized methods for the analysis of environmental aspects and potential impacts of products, processes, and organisations from a life cycle perspective. A LCA usually covers two dimensions of sustainability (ecological and economic). Many assessment methods also include the third dimension of sustainability: the social aspects.

This article introduces a new methodological approach—the Adaptive Design (AD) Evaluator, that includes a fourth dimension, "gestalt aspects" for adaptable spatial and social LCAs. We aim to fill the gap in the assessment tools for project ideas and rough concepts within early planning phases. In particular, we address the challenge that there is currently no scope for self-assessment of planning alternatives without requiring external audits. The innovative approach of the AD Evaluator focusses on the support of cooperative planning processes, in which the tool-supported evaluation of project plans and framework conditions provides immediate feedback in decision-making processes. The aim is to create a system with which the automated evaluation of input from local experts and citizens (in the form of project questionnaires and evaluation forms) provides input for system dynamics models (SDMs) for analyzing interactions. The automated preparation and processing of the evaluation results enables a step-by-step improvement of ideas and projects in co-operative processes.

The AD Evaluator underpins sustainable spatial transformation from the idea to realization with a focus on strategic co-design and co-assessment. Project developers and decision makers (municipality, state, federal government) can use the approach offered by the AD Evaluator to carry out independent assessments and compare alternatives. The AD Evaluator thus offers time- and cost-efficient planning support even for very early planning phases, where new ideas and innovations for sustainable spatial transformation can be introduced, and robust framework conditions and objectives can be strategically developed. This enables planning stakeholders in all planning phases to evaluate planning alternatives, considering impacts and interactions, and at the same time identifies necessary measures to achieve objectives in the form of checklists.

2. State of the Art

Within the field of spatial planning, we are dealing with long-term planning perspectives and envision various alternative spatial states. Sustainable development, introduced over 30 years ago with the "Brundtland Report" (WCED, 1987), has become an important planning objective, especially since the UN's commitment to the SDGs in 2015. A natural evolution process is attached to buildings and infrastructures as it is to biological organisms, which initiates continuous transformations within our built environments and allows for sustainable transition (Cairns & Jacobs, 2014) and circular economy thinking. The reorganization, renewal, and replacement of built environments within the boundaries of settlement areas are key elements for strategic pathways to sustainable transformation (Schartmann & Siedentop, 2024). However, the challenge for many involved in planning is not whether but how sustainable change can occur. The introduction of spatial sustainability in standards (ISO 59020, 2024) has raised awareness of soil as a resource and the intensity of material drain in the construction sector (35% of waste generation and up to 12% of GHG emissions based on European Commission, 2024). However, there is currently no practical methodology that ensures sustainable building development.

2.1. Spatial Assessment Procedures

On a formal, legal level assessment systems based on EU directives such as the strategic environmental assessment (SEA) or the environmental impact assessment (EIA) are well established. In Austria, they are applied to large projects often related to technical or social infrastructure developments covering time and cost-intensive processes. SEA and EIA are preliminary assessments, particularly in the early planning and design phase of a construction project or of a plan/program. These procedures aim to assess and optimize the sustainability and environmental compatibility of a project as well as planning alternatives at the conceptual level. Additionally, there are further spatial impact assessments for bigger projects in Austria in five federal states on the supra-local level (Upper Austria, Carinthia) and on local level (Lower Austria), as well as when preparing major projects (Salzburg, Burgenland; cf. Stöglehner, 2023). They focus on environmental assets and material assets (Fürst, 2008, p. 71, as cited in Stöglehner, 2023).

Certifications as mentioned above offer standardized approaches assessing projects within the LCA frameworks based on specified plans and building designs via thematic categories. Most certifications are based on the ISO 59000 family of standards for harmonizing understanding, implementation and measurement of circular economy. The ISO 59020:2024 document (ISO, 2024) explains that the system boundaries of the measurement and assessment should be considered in spatial and temporal manner and their impacts to social, environmental and economic systems. The assessment of impacts on these three pillars is based on LCAs.

There is a broad consensus in the scientific literature that certification and testing systems have successfully contributed to raising general awareness of sustainability principles (Garde, 2017). However, not all certification procedures fulfil all essential LCA criteria (Doan et al., 2017). At the same time, due to different evaluation criteria, the rating of a building differs between the various rating systems; the same building is rated “green” or “sustainable” depending on the rating system in question (Suzer, 2019).

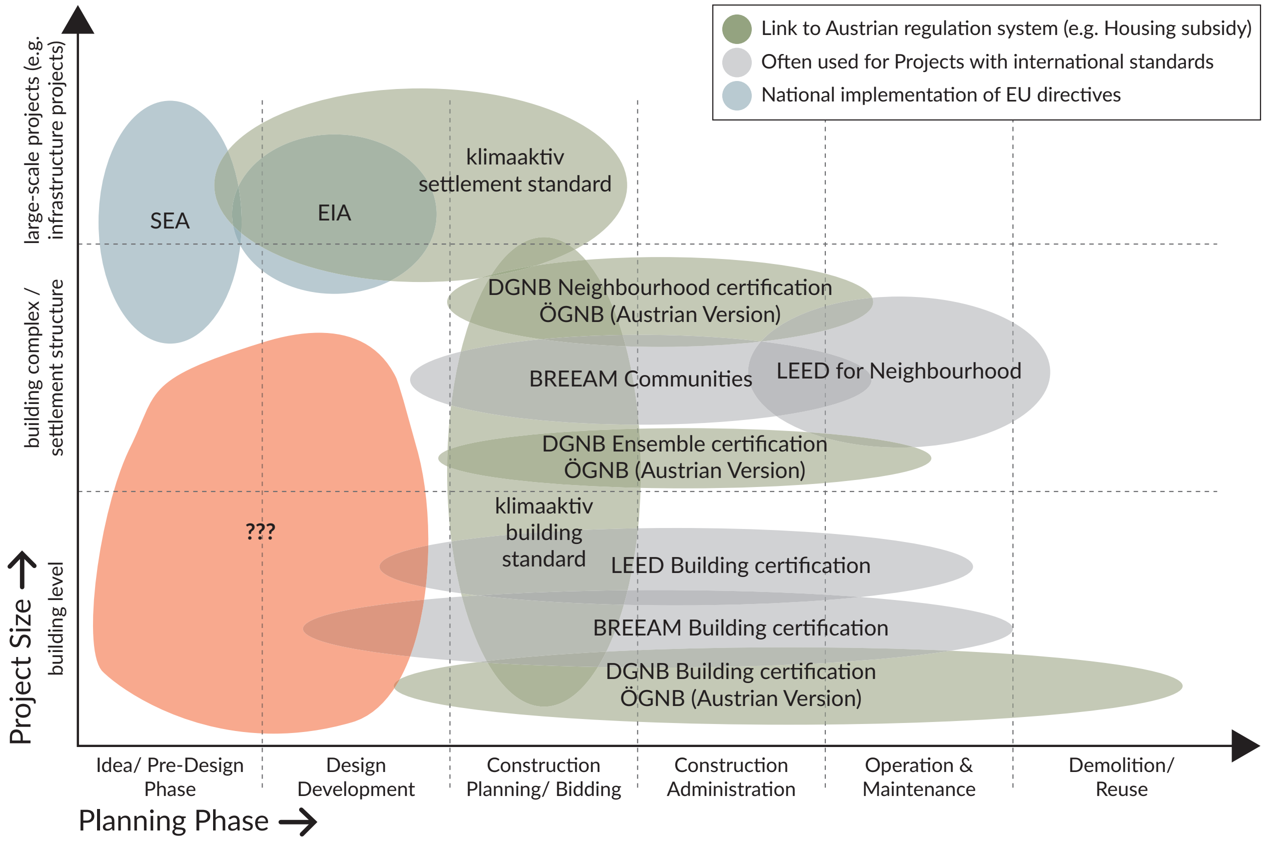
In Austria, the “*klimaaktiv* building standard” is a seal of quality for sustainable construction and refurbishment, an initiative by the Austrian Federal Ministry (BMK, 2024). Property developers, planners, and builders can evaluate constructed or renovated buildings online and free of charge within a defined catalog of criteria. At neighborhood level, expert process support is offered to ensure that the quality criteria are met within the defined fields of action. While common certification systems (ÖGNI/DGNB, LEED, and BREEAM) can assess concrete projects based on detailed plans and designs, there is no assessment available for very early planning phases in the absence of specific building/project designs. All assessments based on certifications and testing procedures are linked to external audits during the assessment process (cf. BREEAM, n.d.; DGNB, n.d.; ÖGNI, n.d.; USGBC, n.d.).

As already mentioned, external audits are time- and cost-intensive processes. Thus, they are more likely considered for large projects as well as projects with great importance on high planning levels. However, it is important to evaluate the large number of medium-sized and small projects and ideas (having a cumulated large impact)—best at an early stage, since not much time and money has yet been spent on the exact planning and design implementation. However, in such cases, details are often lacking. Nevertheless, assessments within early planning phases are essential for efficient planning of sustainable transformations, allowing the definition of project target settings within the sustainability framework of superordinate institutions (municipality, nation, EU). While SEA and EIA enable the assessment of planning alternatives, there is no documentation of planning alternative assessment within building or neighborhood certifications systems. Moreover, available pre-assessments only prepare specified projects for easier assessment within defined categories in the continuing building certification process.

Figure 1 provides an overview of existing evaluation systems and shows their use in relation to the planning phase and project size. The boundaries between the different evaluation systems are blurred. The systems are not transparently documented and focus on diverse aspects. The diagram illustrates a gap within early planning phases on building and community level. This lack of opportunity for assessment in early planning phases, especially in the governance processes and in the informal planning and decision-making processes, has also been identified by the German Federal Office for Building and Regional Planning (cf. BBSR, 2020).

2.2. Digital Assessment Environments

Certification systems assess within fixed categorization grids. They are subject to extensive, rigid, but not project-specific evaluation systems. In addition, LCAs have a static structure which does not consider dynamic influences (Fouquet et al., 2015). Within environmental scenario analysis, dynamic effects and interactions must be taken into account (Yi et al., 2023). An SDM is described as a feedback control system using digital simulation for complex system analysis and improvement (Forrester, 1961). In recent years, the combination of SDM and LCA has been a common means of providing for decision support (Choong & McKay, 2014). The integration of SDMs into assessment processes in the field of LCA enables static relationships to interact dynamically with each other and thus to simulate changes directly, as well as to analyze the effects of a product throughout its entire life cycle (Yi et al., 2023).



SEA ... Strategic Environmental Assessment
EIA ... Environmental Impact Assessment
DGNB ... German Sustainable Building Council (https://www.dgnb.de/de)
ÖGNB ... Austrian Sustainable Building Council (https://www.oegnb.net)
LEED ... Leadership in Energy and Environmental Design (https://www.usgbc.org/leed)
BREEAM ... Building Research Establishment Environmental Assessment Method (https://breeam.de)

Figure 1. Positioning of the AD Evaluator concept study in relation to existing evaluation systems for the sustainable development of cities and buildings in the German-speaking planning area.

The methodological approach envisaged in this article involves using questionnaires to query and map objectives, as is in certification systems, but automatically transfers predefined categories, including their weighting, into simple SDMs. Assunção et al. (2020), Diemer and Nedelciu (2020), and Kiss and Kiss (2021) have already conceptually demonstrated such an approach in various studies. Automating these steps could efficiently provide assessments for planning practice "at the push of a button," in contrast to previous approaches, which have lacked transparent, transdisciplinary, digital tools (Stede et al., 2024).

Meanwhile, certification providers are increasingly offering digital tools that visualize the guidelines for sustainability certification as early as the pre-assessment phase. The digital integration of certification assessment systems aims to meet the demand for digitally driven sustainability transformation, as called for in a report by the German Advisory Council on Global Change (WBGU, 2019, p. 9). However, these procedures are designed for a defined project and are not used for joint project development but to fulfil the sustainability goals for an already defined project. There are currently no known assessment approaches that automatically create a comprehensible basis for decision making and list recommendations for action in a digital framework at a very early concept phase for the various stakeholders. Early involvement of communities or users is not provided within existing certification processes (Saiu et al., 2022). Inclusion of these stakeholders could go a long way to closing knowledge gaps in early planning stages. Schönwandt (1999) and Selle (1997) emphasize the need for cooperative processes for the development of robust planning decisions. D'Ignazio and Klein (2020) show how social and gender-relevant aspects in cooperative planning can also be integrated.

2.3. Gestalt Sustainability and AD

The term and concept of gestalt sustainability emphasizes the necessity of considering not only ecological, social, and economic factors but also the qualitative dimension of spatial design (Pansinger & Prettenthaler, 2023). This dimension acknowledges that the physical form and arrangement of spaces profoundly impact quality of life, social interaction, and ecological balance. Gestalt sustainability refers to the intentional design of spaces that fosters interactions between people and their environment, crucial for developing resilient urban structures that are both adaptable and sustainable (Gehl, 2011; Lefebvre, 2001; Sassen, 2000). A space designed according to the principles of gestalt sustainability facilitates harmonious interaction among various aspects of life, promotes community spirit and cultural identity, and supports ecological principles (Pansinger & Prettenthaler, 2023). We therefore adopt the term "adaptive design" in describing our approach.

The impact of digitalization and related technologies on spatial structures is analyzed by Radulova-Stahmer (2023). Based on the analysis of direct interventions (sharing concepts, energy production, waste management, etc.) and indirect drivers (changes in mobility behavior, intelligent lighting, shifts in use, etc.) spatial impact categories and their limits are identified. These spatial impact categories are differentiated by changes in human behavior, in the physical urban space, and in the overall spatial system. Organized into spatial impacts and potentials, they can form a broad basis for deriving qualities for a gestalt sustainability assessment.

3. Methodology

First, the main concept of the AD Evaluator is described, based on the methodological approach for its development. Afterwards the concept study of AD Evaluator is tested based on a case study area in Austria.

The overall research approach of the AD Evaluator is a test procedure that makes it possible to assess whether the objectives of the planning project fit into the overarching system and where there is potential for improvement, both at development (project organiser) and system level (municipality, country). The AD Evaluator employs a systematic approach to assessing and designing urban spaces, considering both quantitative and qualitative dimensions. Figure 2 presents the AD Evaluator process based on the four phases: base setup, preparation, assessment, and co-evaluation.

1. Base setup phase: The initial base setup is performed by planners and experts and creates the relevant test framework by selecting the (sustainability and policy) objectives. These shape the questionnaires and weighting tables that are filled in the following phases. First categories are defined, which allow spatial sustainability to be mapped. Based on the defined AD Evaluator criteria catalog a scheme for questionnaires is designed. All criteria are assessed based on linked measures as well as interconnections and connections with each other by expert groups also for further use within the evaluation phase.

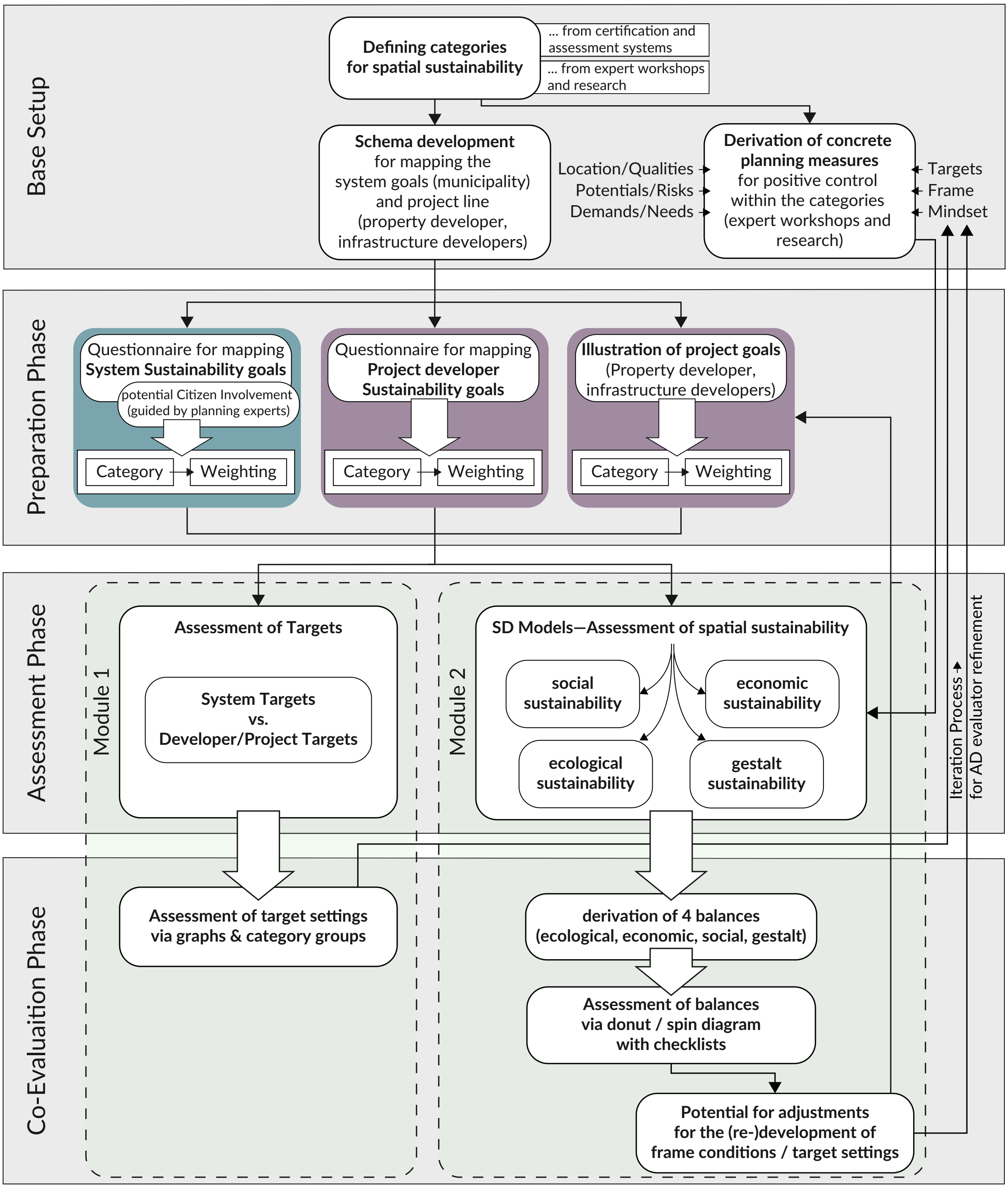


Figure 2. AD Evaluator concept—Methodological approach overview.

2. Preparation phase: Based on these categories, a three-stage "framing" approach is developed. The framing process enables a holistic systemic assessment of spatial sustainability by means of questionnaires, which allow us to derive the following objectives:
   - The superordinate system objectives (objectives of the municipality, country, SDGs);

    - The project developer objectives (property developer, infrastructure developer, etc.);
    - The specific project objectives.

   The questionnaires are linked to the predefined categories and allow objective-based weighting.
3. The assessment phase consists of two main modules:
    - Module 1 allows comparison of system versus developer (project) targets based on category groups and weighting within each objective "frame."
    - Module 2 is based on the evaluation of SDMs, where the categories including weighting serve as input. The SDMs capture interactions and interdependencies and enable the assessment of spatial sustainability in social, ecological, economical and gestalt-related areas. The SDMs examine potential designs through defined rules of action. These defined effect mechanisms allow the development of comprehensible results and the comparison of results.
4. The co-evaluation phase is also divided into the two modules shown in the assessment phase.
    - Module 1: The outputs can be compared based on graphs which illustrate the superordinate system target settings versus the project objectives. The characteristics of individual evaluation areas are described by means of main groups containing several AD Evaluator criteria.
    - Module 2: The output of the SDM is a "SPace INdex (SPIN)" holding the main sustainability categories (ecologic, economic, social, and gestalt), assigned subcategories, and the characteristics of a specific development alternative within these categories.

Additionally, the output contains a checklist with the most important points for ensuring targeted implementation within the defined sustainability conditions from both a system and developer view. The visual and textual output allows evaluation and comparison of development alternatives as well as clear structural information online achievement.

In the following, each step from base setup, preparation phase, assessment phase, and co-evaluation phase will be described in detail.

3.1. Base Setup

The *criteria selection process for sustainability assessment* are derived from the three most important standards for building and neighborhood assessments in Austria, ÖGNI and *klimaaktiv* building standard, and are expanded with spatial impact categories defined by Radulova-Stahmer (2023).

Based on the criteria categories from building and settlement catalogs within these systems, a criteria list is extracted and prepared in such a way that multiple entries and overlaps are avoided. This step was executed with table sheets using a line-by-line manual preparation.

The resulting criteria list allows us to derive spatial measures. Based on these measures the AD Evaluator criteria catalogue (AD criteria catalogue) is defined, allowing project descriptions and scheme development. The criteria are clustered in five thematic categories:

1. Land use and urban fabric
2. Resources and environmental aspects
3. Mobility

4. Quality of stay
5. Governance and participation

Attachment 1 in the supplementary file presents a starting point for this catalog.

For the *scheme development* the sustainability assessment is built along the three dimensions of sustainability (ecology, economy, social) used in LCA approaches supplemented with the important fourth dimension "gestalt." In the context of the AD methodology, gestalt sustainability is viewed as an integral component of planning. Within the AD Evaluator, this integration is accounted for by embedding four main criteria:

1. *Recognizability/Clarity* (see Figure 3a): This dimension evaluates and promotes a transparent spatial organization and a clear identity that helps users intuitively navigate and utilize the space. "Connectivity clarity" is shown through the logical connection of function, space, and infrastructure, for example, by the deliberate arrangement of buildings and their connection to infrastructure. "Usage clarity" arises from clear organization that distinguishes historical and new functions while maintaining flexible usage without losing the building's identity. "Figure Clarity" is shaped by the functional and topographical anchoring of the spatial organization.
2. *Communication/Scale* (see Figure 3b): Evaluates the interaction of a space or building with its surroundings and the integration of different scale levels. "Field formation" creates clear boundaries and concise communication. "Affinity" ensures that the area harmonizes with its context, with material choices, shapes, proportions, and functions determining the relationship to the surroundings. "Mediating scale" ensures the harmonious interaction of different scale levels by balancing size differences and supporting both the functionality and aesthetics of the ensemble.
3. *Openness/Topological boundary* (see Figure 3c): Evaluates how a spatial system forms a boundary that separates and connects through physical, symbolic, and functional transitions, enabling the exchange of information and accessibility. "Contextuality" connects the spatial organization through symbolic and functional boundaries to its environment. "Permeability" creates smooth transitions between interior and exterior spaces, both physically and symbolically, opening communication with the surroundings. "Symbolic boundary" serves as a gateway to the history of the place.
4. *Adaptability/Transformability* (see Figure 3d): Evaluates a system's ability to adjust to changes while preserving its identity. It includes: "Place character" as the unique atmosphere of a place, shaped by architecture, nature, culture, and history; "Short-term and longevity" as the ability to adjust to new uses in the short term while maintaining cultural significance and flexibility in the long term; "Adaptability" as the ability to integrate societal and functional changes without losing the fundamental structure or identity.

The AD Evaluator approach leads to a tree-based scheme of four qualitative balance sheets, based on AD-criteria:

1. Ecological balance
2. Economic balance
3. Social balance
4. Gestalt balance

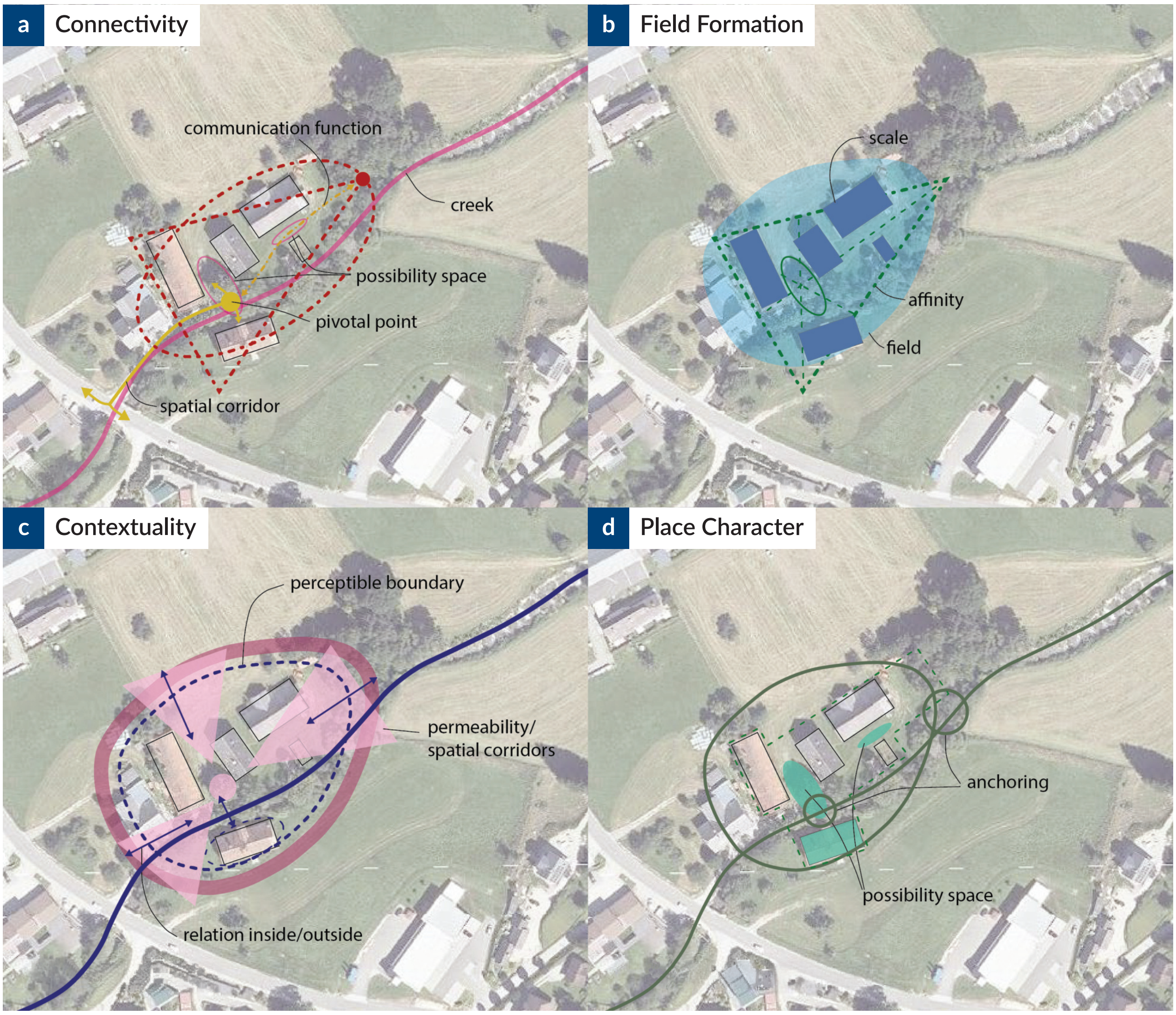


Figure 3. Four main criteria of gestalt: (a) Connectivity/Clarity, (b) Field Formation, (c) Contextuality, (d) Place Character.

These balance sheets are calculated via categories derived from the AD criteria catalog. The complexity and interrelationship of these balances and their influence on each other is illustrated in Figure 4 and demonstrates the need for an SDM. Their dependences and interconnections can be illustrated within tree diagrams (see Figure 4a). Within this step the innovation lies within the connection possibilities: The subtrees for the four thematic balances are not pure trees, but a complex system of directed acyclic graphs as they are connected in a causal loop diagram. A child node has several parent nodes (see Figure 4b-II) and at the same time can have several child nodes of its own (see Figure 4b-I). The diagrams show that cyclical relationships also arise, so-called feedback loops, which are represented in an SDM as reinforcing loops (r-loops) and balancing loops (b-loops), or also delayed loops. This makes it possible to recognize complex relationships and effects that may not be visible at first glance.

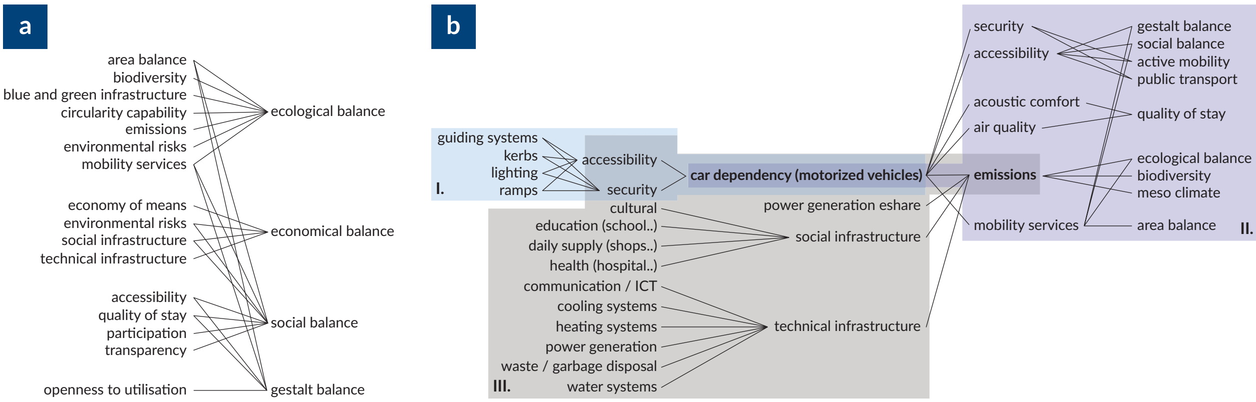


Figure 4. Sustainability concept on four pillars: ecological balance, economic balance, social balance, and gestalt balance (a) and node impacts based on example variable "car dependency" (example selection) (b).

3.2. Preparation Phase

The preparation phase initializes the user inputs to obtain system, developer, and project objectives. The questionnaires are set up based on the detailed scheme beforehand. Furthermore, a method for automated processing of questionnaires is described. In order to achieve this, the questions used to describe the project plans and their effects follow a predefined syntax, which is shown in Table 1. The property lists and objectives are fed for automatic processing from a growing pool that was initially created in the base-setup phase.

The following essential steps to enable project evaluation within the three-stage framing approach are necessary:

To obtain system objectives:

1. Set up the policy goals (e.g., SDGs, climate targets for Lower Austria, etc.) and describe their impact on the four sustainability pillars (see Table 2);
2. Weight the policy goals from 0 (not important) to 5 (very important; see Table 2) and assign temporal context.

To obtain project objectives:

3. Choose project activities/features from the "AD criteria catalog" to build the questionnaires that query specific projects and plans (see Attachment 1) and identify their impact (positive/negative/neutral) to the policy goals via a matrix.

To obtain developer objectives:

4. Query developer mindset on policy goals.

As already shown in the scheme development section, the project description is consistently based on the mapping of the effects in the four balances and the subgraphs with interconnections and different nodes.

The development of questionnaires is based on the nodes within the scheme graph. Some nodes show both location-related features and project-related features.

In our method, we derive three types of questions for the questionnaires:

- Type 1: General questions on the location, describing risks, potentials, and qualities including respective demands (like a SWOT analysis).
- Type 2: Questions related to project impact on location—specifically on risks, potentials, and qualities and demands. This question set forms the complementary question set for 1. to map the effects of the project.
- Type 3: Questions to describe the project qualities from AD-criteria catalog (can be extended as required).

These questions can be reduced and simplified for automated processing to the syntax illustrated in Table 1.

Notes related to Type 2: For the purposes of conceptual presentation, the time horizons are initially broken down into the categories short-term, mid-term, and long-term. The definition for the three units can be determined jointly by the stakeholders in the communication processes or, depending on the complexity of the SDMs used, must then be clearly specified in temporal contexts (e.g., years).

Notes related to Type 3: A list of qualities that were queried during the use case analysis (Chapter 4) can be found in Attachment 1.

3.2.1. Query System Objectives

While using the AD Evaluator, the objectives to be considered can be individually adapted to municipal, regional, and overarching objectives. Therefore, the actors representing the "system view" (representatives of municipalities or government administration, planning department) will describe their policies and assess the impact on sustainability (see Table 2). Table 2 shows an example of how the influence of the objectives/goals on the four pillars of sustainability (ecology, economy, social issues, gestalt) is assessed. The different objectives are also weighted in relation to each other from 0 (non-goal) to 5 (high importance) and placed in a temporal context (short-/mid-/long-term). Together these describe the sustainability and policy objectives that have been selected in the base setup.

3.2.2. Query Project Objectives

Type 3 question outputs describe project objectives and allow us to derive a connection to policy objectives. This allows us to rate single criteria and offers the option to display desired behaviors or project characteristics. The effects of project characteristics on the defined policy objectives can be presented in three categories: positive, neutral, negative. In a programmatic implementation of the AD Evaluator tool, this can also be shown as numerical values (e.g., from +5 to −5).

Table 1. Automated processing of question types.

Type	Question	Answer	Example
Type 1: General questions about location	“Risk xy in Area”	[No! | Don’t know! | Yes + Risklevel 0–5] (level 5 high, e.g., annually; 0 not in a lifetime)	Q: Is your project location in a flooding zone? A: Yes—Risklevel 3 Q: Is your project location in a drought zone? A: No! Q: Is your project location in an earthquake zone? A: Don’t know!
Type 1	“Potential xy in Area”	[No! | Don’t know! | Yes+Potential level 0–5 (level 5 high, 0 not feasible)]	Q: Is your project location in a wind zone? A: Don’t know! Q: Is the area suitable for solar power generation? A: Yes! Potential level 4
Type 1	“Quality xy in Area”/“Demand xy in Area”	[No! | Don’t know! | Yes+Level 0–5 (level 5 high, 0 not existent)]	Q: Public transport quality in area? A: Yes, 3. Q: Accessibility quality in area? A: Yes, 2. Q: Demand for social housing in area? A: 5. Q: Demand for social infrastructure “elementary school”? A: 4.
Type 2: Project impact on risks, potentials, demands, qualities of location A1: [yes-increase]	Project effects “Quality xy/potential xy/risk xy”?	[yes-increase | yes-decrease | no-neutral]	Q1: Does project effect “quality of public transport”?
+ Impact estimation over time	How would you rate the impact of the project on XY over time?	[short-term 0–5, mid-term 0–5, long-term 0–5] (impact 5 high, 0 none)	Q2: How would you rate the impact of the project on “quality of transport” over time? A2: [2, 5, 5]
Type 3: Qualitative project description using predefined list of criteria/activities/ features [A/F]	Does your project or plan involve [A/FAD criteria from AD criteria catalogue]?	[5–0] (Fully applies 5...does not apply 0)	Q: Does your plan involve “new building land dedication”? A: 0 Q: Does your project involve “improving walkability”? A: 3

3.2.3. Query Developer Objectives

Developer objectives are queried in the joint process related to project objectives and system objectives queries. For this purpose, an assessment of the developer is collected in relation to individual categories (from the project objectives questionnaire) that are linked to the system objectives (from the system objectives questionnaire) in the background. In this way, an assessment of the developer’s mindset in relation to the system objectives can be created.

Table 2. List of (example) goals and their influence on the dimensions of sustainability resp. their priority of time.

Goal		Sustainability pillars				Priority (over time)		
ID	Description	Ecology	Economy	Social	Gestalt	short-term	mid-term	long-term
g1	Clean water and sanitation	0–5	0–5	0–5	0–5	0–5	0–5	0–5
g2	More social housing	0–5	0–5	0–5	0–5	0–5	0–5	0–5
g3	Reduce soil sealing	0–5	0–5	0–5	0–5	0–5	0–5	0–5
…								

Notes: Exemplary presentation for better readability: 5…high impact on pillar, 0…no impact on pillar; 5…high priority, 0…no priority.

3.3. Assessment Phase

The project is evaluated in parallel from both a system perspective (e.g., municipality) and a project perspective (e.g., developer). The questionnaires created serve as a means of communication for the evaluation and discussion between the stakeholders.

The assessment process can be processed in two different ways, represented within the AD Evaluator approach with Module 1 and Module 2. Module 1 allows the comparison of system and project perspective for the alignment of target settings within all planning actors. Module 2 calculates balances for holistic sustainability evaluation using SDM for detailed quantitative further assessments

3.3.1. Module 1: Assessment of System and Project Perspectives for Stakeholder Alignment

The project is evaluated in parallel from a project and system perspective using the project documents provided and the idea presented. Based on this, questions about the project characteristics (question type 3) are answered. The differences as well as the similarities can be (automatically) determined and highlighted.

Fields of actions and checklists including specific measures can be dynamically derived from evaluated differences. Different project alternatives (scenarios) can be individually addressed by also comparing project alternative objectives and system objectives, inducing a comparison of identified opportunities, risks and demands (question types 1 and 2). For cooperative planning support, different future scenarios can be stored and presented by modeling the system assessments in a programmatic implementation.

3.3.2. Module 2: SDM Concept

To enable mapping of interactions between the sustainability balances based on the desired activities and projects, the inputs of the programmatic implementation are transferred to an (initially simplified) SDM. That model can be built using the assignment trees and properties (nodes) of the location and project. Location related characteristics (spatial, social, etc.) are to be considered as stock variables in the SDM—they are represented in the questionnaires by question types 1 and 2. Project characteristics (questionnaire question types 3) affect these stock variables and form the input parameters for the description of inflows and outflows. To link the SDM to the policy goals, target variables need to be identified. They also need to be considered as stock variables in the SDM. If they are not already included in the SDM, they need to be created and integrated.

3.4. Co-Evaluation Phase

The co-evaluation phase is linked to the chosen module within the assessment phase. Each module enables visual output for quantitative and qualitative feedback.

Module 1: For cooperative planning support processes multiple diagrams based on main groups within the AD catalog (see Attachment 1) are generated (e.g., Figure 8 from case study analysis). Additionally, a checklist is produced to estimate environmental impacts. This also forms a basis for the time allocation and structuring of measures.

Module 2: The generated SPIN chart allows us to detect quantitative characteristics within specific sustainability balances, which in turn allows the detection of precise adaptation of measures. In cooperative planning processes, this can initiate an iterative improvement process for project adaptation on the one hand, and for the systemic framework conditions on the other, to create long-term holistic sustainability. The checklist of measures, which is also generated in this module for evaluation, creates a basis for communication of the impact analysis on the environment. At the same time, it also provides a good basis for early cost estimation, due to the derivability of construction requirements.

4. Case Study Analysis

4.1. Location and Embedding: Zellerndorf in Lower Austria

Zellerndorf is a small municipality (around 2,400 inhabitants) in the federal state of Lower Austria (Niederösterreich NOE) located 70 km north of Vienna. It has a line-oriented village structure with a school and sports center in the middle, defining a center for inhabitants and cultural interventions (see Figure 5), where just under half of the inhabitants live. The other inhabitants live scattered in smaller villages in the surrounding area. The municipality deals with challenges related to degrowth, an ageing population, and a lack of a central place for joint activities. Thus, the municipality wants to focus on sustainable development paths. Based on an empty plot (total area 4,000 m²) with a central location, a spatial assessment is stimulated. Within this case study analysis, two building developments with different usages are evaluated: Project 1—Multi-generation living, and Project 2—Supermarket—local supplier.

Project 1—Multi-generation living: Within the case study area, a project focusing on a multi-generational housing concept is evaluated. The project focuses on a vacant area of approximately 4,000 m². The project will cover about 1,800 m² and deals with four building complexes (each 450 m²) with 28 apartments for three generations (ages: 20–55, 55–75, 75+). The buildings form three atriums (450 m² each) enabling semi-public green spaces, offering shaded seating and social interaction. The remaining area will be used as a parking lot (750 m²).

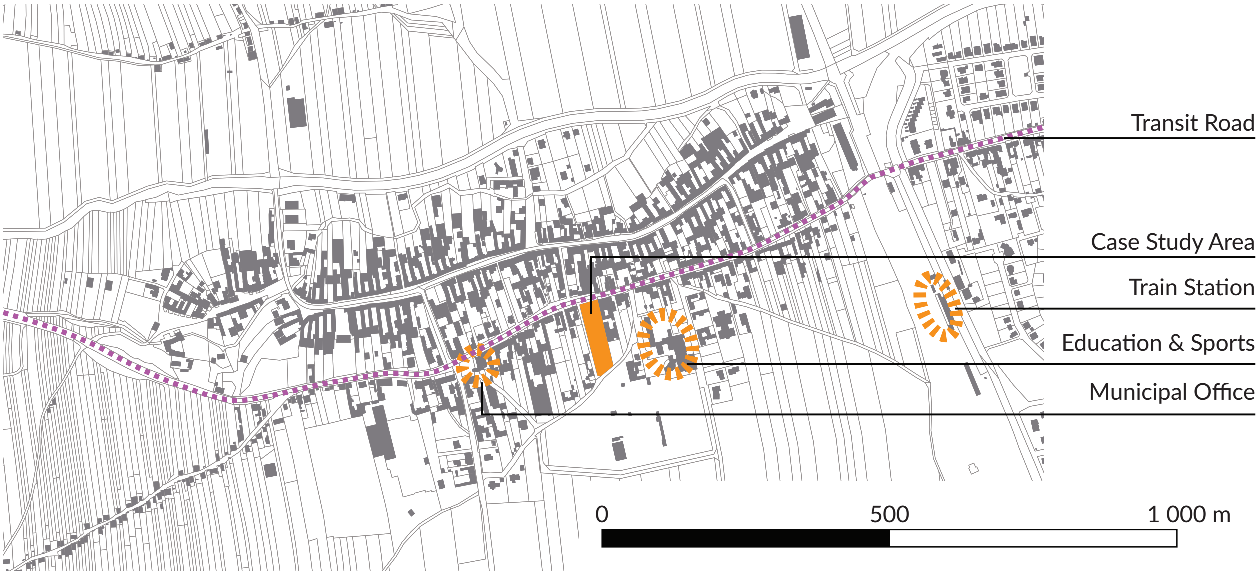


Figure 5. Plan of the village illustrating location of case study area related to structural embedding and accessibility.

Project 2—Supermarket: Within the case study area, a supermarket offering regional supply with food and essentials for daily life is evaluated. The project covers about 2,200 m² within one building and replaces the existing smaller supermarket in the neighboring building. The remaining area will be used as a parking lot (1,800 m²).

4.2. Preparation Phase

4.2.1. Description of Targets of the Specific Policy Framework

Both developments in the case study are evaluated on the basis of the policy goals (SDGs + NOE climate targets). The goals are entered in a table (analogous to Table 2) and prioritized from the perspective of the municipality. The definition of this perspective within the AD Evaluator was carried out by us, based on discussions with community representatives, the local planner, citizens, and the existing regional development strategy. The resulting weighting of the policy goals is shown in Figure 6 and applies to both tested projects. The priority of goals is shown in short-, medium-, and long-term as well as in a cumulative presentation. The darker the colour of the entry, the more important the target is considered to be. The priority shown refers only to the project characteristics selected for evaluation (= subset of Attachment 1; see Step 3 in preparation phase description) and shows the relevance of the goals for the chosen evaluation setup.

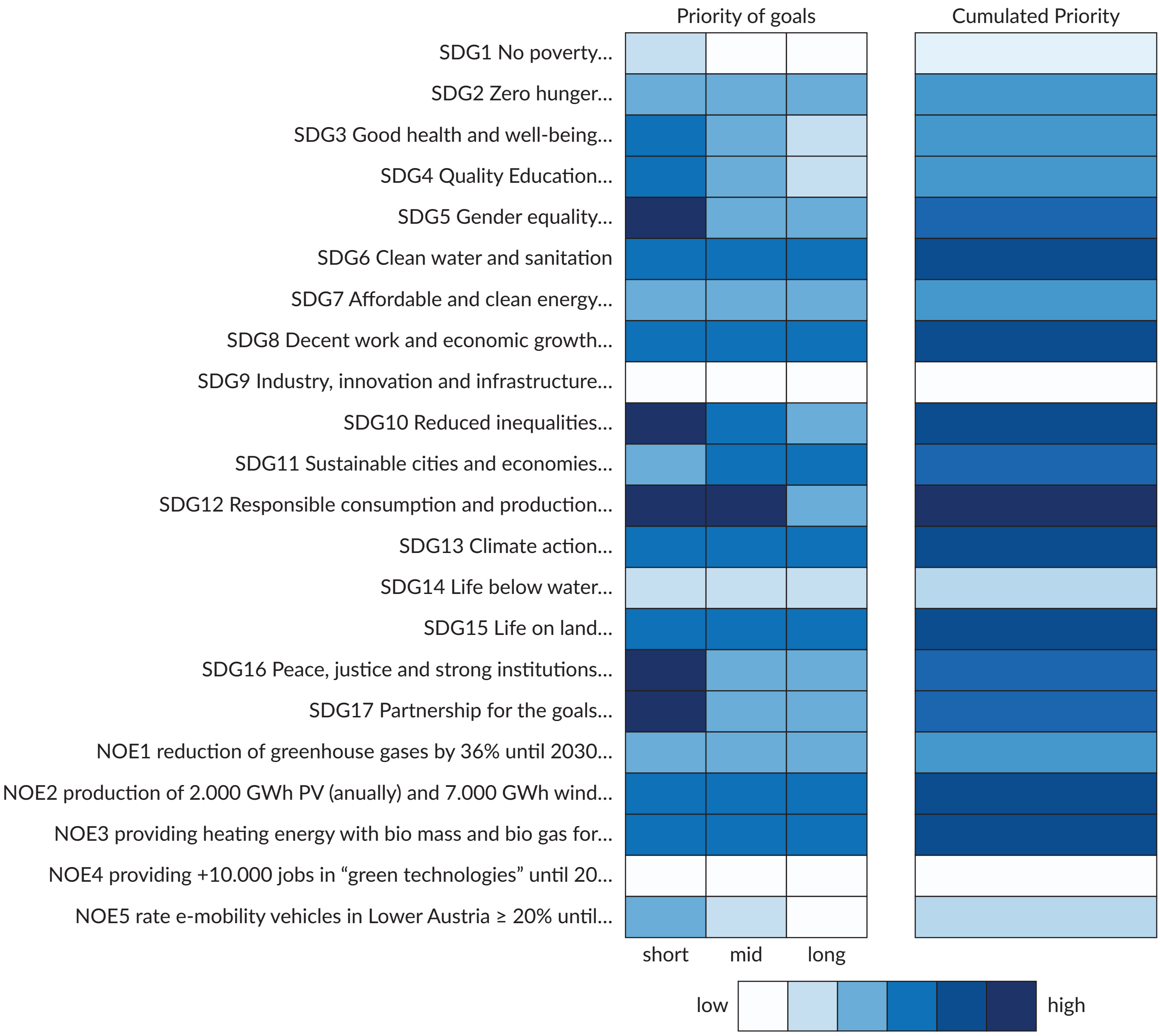


Figure 6. Weightings of the sustainability/policy goals from the perspective of the municipality for the project characteristics selected for evaluation and their priorities in short-, mid-, and long-term perspective.

4.2.2. Description of the Project Activities and Features

As the case study involves two different project plans and uses for a specific property and not theoretical concepts and plans, the criteria catalog in Attachment 1b is used. After defining the effects [positive|neutral|negative] of project characteristics/activities on political goals and expectations ("system perspective"), it is also possible to analyze the derived impacts of activities and characteristics over time. Figure 7 shows the effect of a selection of the project characteristics/activities on the objectives of the municipality. A distinction is made between expected short-, medium-, and long-term impacts. This allows us to identify those measures that have a major influence (positive or negative) on the municipality's objectives. For example: While the project characteristic "unsealing soil" (#2017) has a positive effect in terms of the defined goals of the municipality, projects that have "fossil fuel heating systems" (#2036) have a negative effect on the formulated objectives.

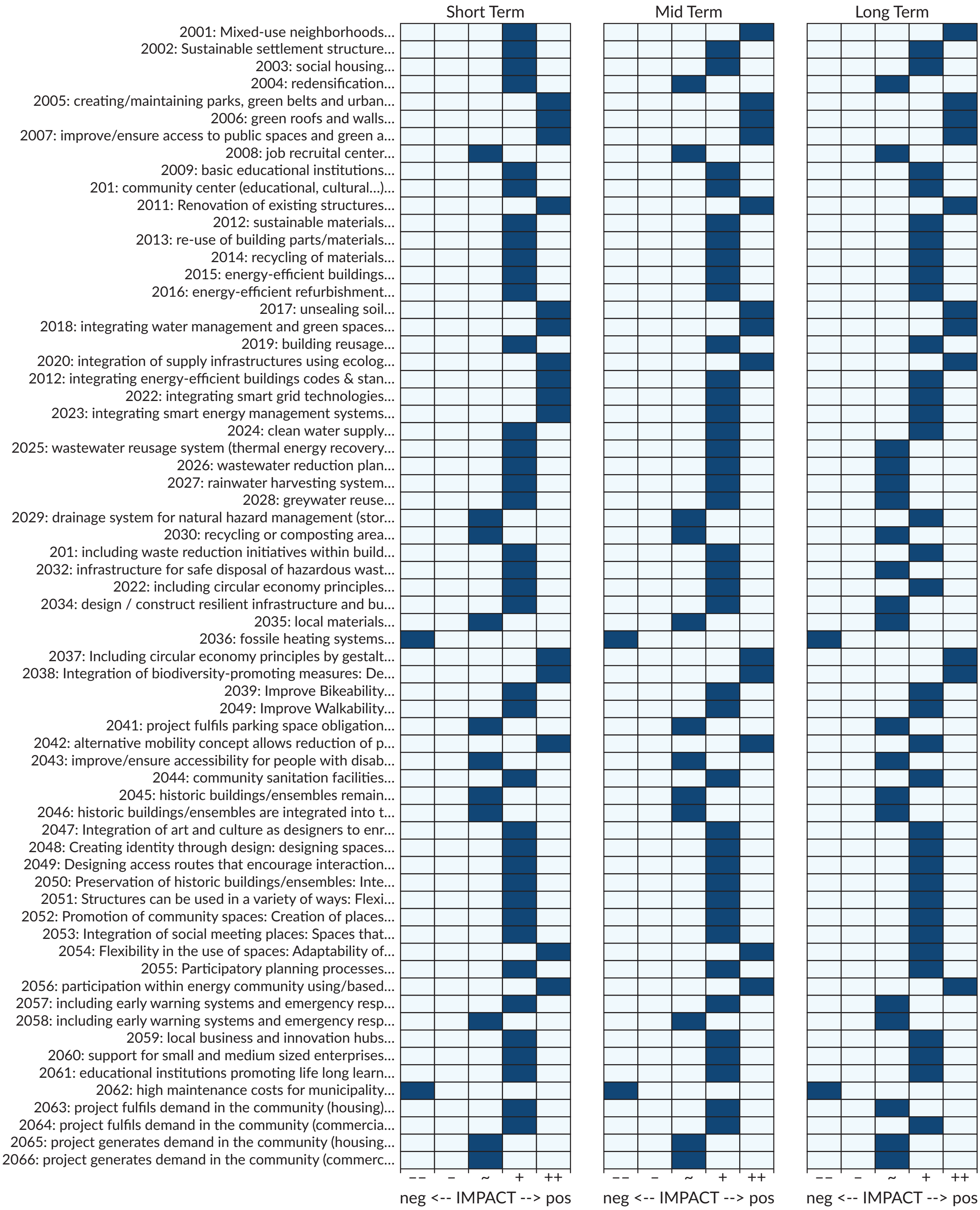


Figure 7. The impact of (a subset of) project feature characteristics, derived from the priority of the policy goals in the short-, mid-, and long-term.

4.3. Assessment Phase

The challenges, qualities, and objectives of the project area are briefly outlined below. Based on these descriptions, the respective project characteristics are evaluated, and it is shown that each of the two projects addresses different criteria.

4.3.1. Risks, Potentials, Qualities, Demand in Area

There was a slight demand for starter flats for young people and for small flats. There is no institutional care for the elderly. Property prices are still favorable compared to the immediate surroundings of Vienna and the journey time by S-Bahn to Vienna is around one hour. The current supermarket will be closing as the owner is retiring.

4.3.2. Project Impact on Risks, Potentials, Demands, Qualities of Location

The housing project could meet the need for housing and stimulate demand. The supermarket project would secure local supplies in the municipality for the coming years. The location in the centre of the built-up town center is very suitable for both uses.

4.3.3. Assessment of Projects

The separate and individual evaluation of the project characteristics based on the known project information yields the following initial findings for Project 1: 54 characteristics were used for the evaluation, whereby eight criteria were assessed equally from a system and developer perspective. In a further seven criteria, the expectation/requirement was exceeded from a system perspective. In 16 criteria, there were minor deviations, whereas the requirements were clearly not met in 23 criteria.

For project 2, 52 criteria were considered in the evaluation, whereby eight were assessed equally and four exceeded the requirement from a system perspective. Minor deviations were detected on 13 criteria and 27 criteria clearly do not fulfil the requirements. Two characteristics were not considered for evaluation as they apply specifically to residential construction projects only.

4.4. Co-Evaluation Phase

4.4.1. Module 1: Evaluate Targets and Objectives

To ensure that the participants in cooperative settings do not get bogged down in details, the biggest differences and deviations in the assessments are prioritized for discussion as a planning base. The differences between the project activities expected and the project activities determined are analyzed statistically based on the project assessment. Various key performance indicators were analyzed so that this can be done automatically. The standard deviation, variance and mean value of the differences are determined for each thematic cluster (see Section 3.1 base setup). Figures 8a and 8b show that the variance and standard deviation are best suited to determining the need for action or discussion.

While the assessments of multi-generation housing (Project 1) differ mainly in Cluster 5: Governance and participation aspects (Cat5 in Attachment 1), the differences in the planned supermarket (Project 2) are mainly in the assessment of the Cluster 4: Quality of stay (Cat4 in Attachment 1). The next step is to take a closer look at the differences in the respective assessments: Figure 8c and 8d show the respective expectations (system view) for the two projects in comparison to the project assessment by system and developer.

Analyzing these differences provides the basis for defining and designing new agreements or modified project specifications. This is to be implemented programmatically in future (see Section 7 Outlook). By digitally recording the questionnaires and entries, the individual measures and expectations can be compared based on a traffic light system on the deviation. Suggestions for improvement, warnings, or recommendations for action can initially be pre-formulated in general terms and then automatically improved using algorithms. By prioritizing the objectives and linking them to the activities, expenditure can be quantitatively limited to a sensible level.

4.4.2. Module 2: SDM

A simple SDM was created based on the assumptions made. The years 2030/2040/2050 were assumed as thetime horizons for the short-/medium-/long-term analyses. However, the selected use case is too small for the two projects to generate different effects in the very generalized model. In general, the model shows that the reduction in motorized traffic leads to a reduction in emissions, and that the improvement in accessibility and the quality of stay in public spaces make a positive contribution to the social balance and the design balance.

The comparison of the projects based on the four sustainability balances in the AD Evaluator shows that Project 1 performs slightly better than Project 2 (see SPIN graph in Figure 8e). The points achieved in the respective balance sheet are normalized based on the expectation value (= 100) from a system perspective. The graph also shows a utopian Project 3, which achieves all possible points. In this result, however, the interactions in the SDM between the individual balances hardly play a role.

Figure 8 shows the evaluation results for the two projects. Figure 8a shows the average of the absolute values of the deviation between system expectation and evaluation, while Figure 8b shows the standard deviation of the evaluation between system and developer evaluation: High values show a high discrepancy between the evaluation of the project from the perspective of the municipality and the evaluation from the perspective of the project applicant. The statistical measures (average, median, standard deviation, and variance) are to varying degrees suitable for identifying the deviations of the different assessments in the respective assessment categories. It turns out that the mean deviation in absolute values of the deviation between the perspective of the municipality and that of the project applicant best highlights the respective differences.

Figures 8c and 8d show the project evaluation of the system and the developer's perspective within the categories with the largest differences (Project 1: "Quality of stay," Project 2: "Mobility"). Figure 8e compares the results of projects in the 4 balances with the expectations of the municipality. The grey line in this figure illustrates a utopian project development, where all points in the respective balance sheets are achieved.

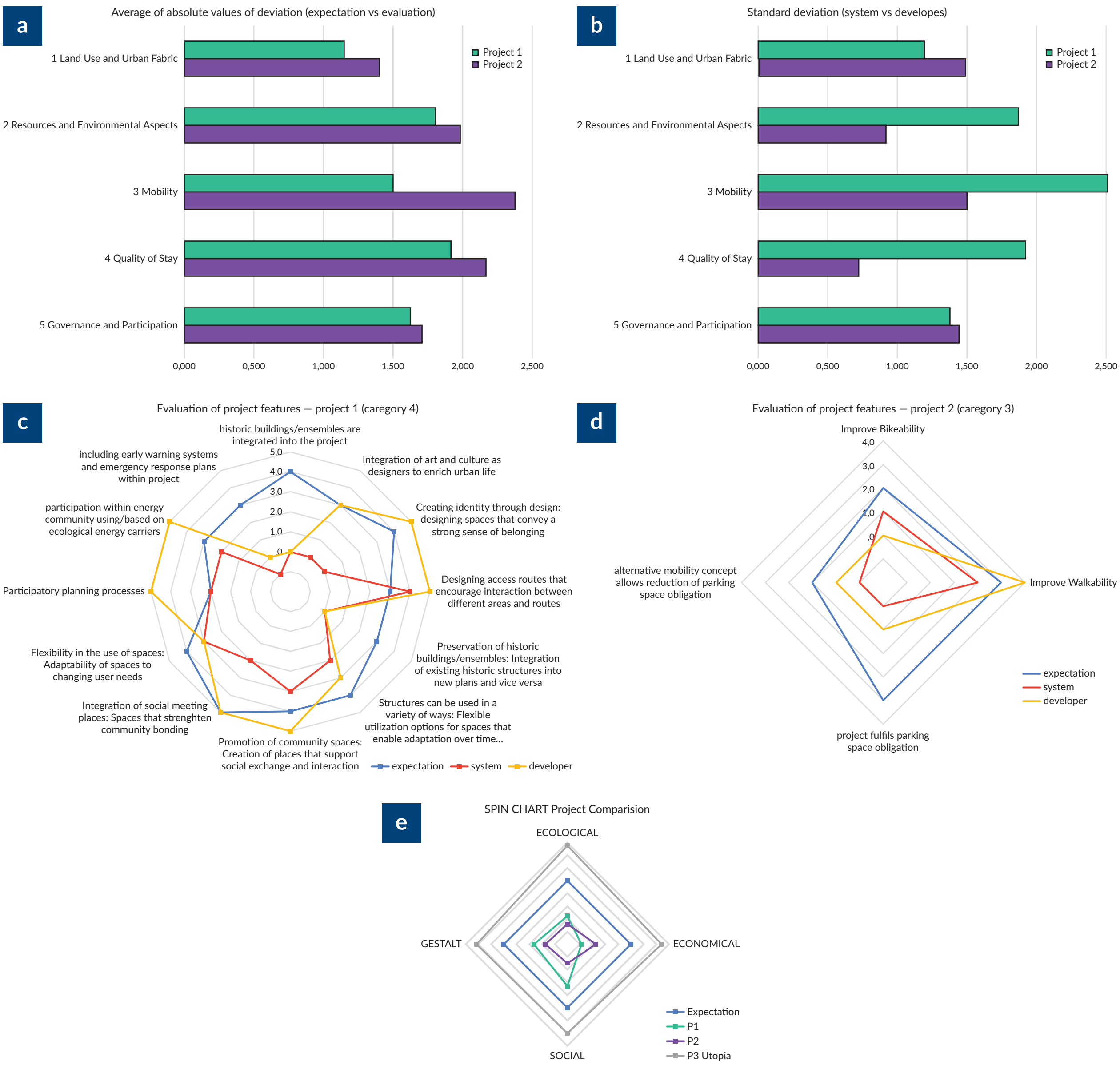


Figure 8. Statistical analysis of thematically clustered differences between expected activities and results of project assessment (a, b); concrete differences in the evaluation of project features/activities between expectations and project assessment: Project 1—Cat 4 (c) and Project 2—Cat 3 (d); and comparison of projects along the four sustainability balances (e).

5. Results

Section 4 has reported the main outputs illustrated in Figures 6, 7, and 8 of the AD Evaluator. Based on these figures, an estimation of the different effects and interactions of each project alternative is possible. The figures constitute a decision support base and allow us to initialise co-operative processes including planners, decision-makers, and citizens. Within these cooperative processes new ideas arise, which iteratively can be assessed again.

The results in Figure 8 show whether there is agreement between project developers and the municipality on the project qualities (see Figures 8a and 8b), where the differences in assessment lie (see Figures 8c and 8d) and how many points the projects score overall (Figure 8e). Figure 8 shows that the five thematic categories are effective in highlighting areas where the municipality's expectations diverge from the evaluation results: For instance, the lower the values in Figures 8a and 8b, the greater the agreement between expectations and evaluation (a), and between the municipality and the project applicant (b). In general, there is greater agreement in the evaluation of Project 1 and the project is closer to expectations.

Figure 8e shows that Project 1 scores higher than Project 2 in three aspects of sustainability (ecological, social, and gestalt) and that Project 2 is "better" only in the economic sustainability pillar. Overall, both projects do not achieve the desired qualities and should be improved. Figure 7 shows that certain project characteristics and impacts, such as No. 2036 "fossil heating systems" or No. 2062 "high maintenance costs," have a particularly negative impact on the municipality's objectives. These findings can subsequently be translated into automated recommendations for action.

Figures 8a and 8b also identify the thematic areas that need to be given special attention in cooperative processes. If there is agreement on a negative assessment, another project option should be considered. If there is disagreement, the project developer may be asked to provide further documentation to clarify critical issues. This will help to determine the extent to which a project fits into the framework conditions and objectives of the municipality. In addition, further steps and recommendations for action can be derived from these findings: The different evaluations in comparison to system expectations in Figures 8c and 8d allow us to determine whether the projects can generally be developed in line with the objectives and where there are levers for improving the project proposal. For example, Project 1 lacks the integration of existing structures, buildings, and social meeting places. The main weaknesses of Project 2 in the area of mobility are the lack of parking and the lack of alternative mobility concepts. Automating this process allows us to generate checklists and suggestions for project developers, and thematic evaluations of the main sticking points for decision makers.

The case study analysis (Section 4) illustrates the innovative approach of the AD Evaluator in enabling planning to support cooperative processes by enabling assessment in early planning phases and generating a communication basis for holistic system views. Even without integrating SDMs into the assessment, the structured questionnaires and illustrations can be used to implement a constructive communication basis for planning and assessment processes. However, at the current stage of implementation, the SDMs are only indicative, as they can only show whether stocks are rising/falling or whether there are positive or negative interactions.

Based on structured questionnaires and visual representations, the AD Evaluator creates a concept that encourages dialogue about holistic sustainability, and which includes different perspectives. These perspectives allow us to identify specific spatial design elements that contribute to the promotion of resilience, identity and mixed use in settlements. Because of its flexible nature, the AD Evaluator can easily adapt to changing circumstances within a planning process. It can therefore support AD that is adaptable to changing needs and contexts, thereby promoting long-term sustainability.

The evaluation approaches in Modules 1 and 2 allow for the visualization of interactions between measures. The impact of design decisions on social, ecological, economic, and gestalt balances can be analyzed and made transparent. By introducing gestalt sustainability into the assessment framework, the AD Evaluator addresses the lack of integration of design aspects in existing sustainability assessment systems, which often only consider technical and environmental criteria. It discusses the need to integrate gestalt sustainability as a fourth dimension into the sustainability discourse in order to ensure sustainable spatial quality and quality of life.

The AD Evaluator differs from traditional systems by including early planning stages for the evaluation of ideas or concepts. It also incorporates design criteria and enables qualitative assessment of spatial developments. The focus on gestalt sustainability contributes to the creation of robust and adaptable spatial structures that can meet future challenges in urban contexts. Most importantly, the AD Evaluator promotes a design approach that is responsive to the needs of the community, thereby strengthening social cohesion and participation. This can be done autonomously, without the need for costly audits. The AD Evaluator is therefore a practical tool to support strategic planning, even for small- and medium-sized municipalities.

6. Conclusion and Directions for Further Research

The AD Evaluator tool-concept supports planning and decision-making processes and offers the following innovations:

- Enables the evaluation of planning alternatives/scenarios as early as the concept development stage
- Can be used even before a concrete project exists and promotes cooperation between different stakeholders
- The early definition of sustainable framework conditions minimizes and avoids potential conflicts of interest in later phases and increases acceptance through participatory processes
- Allows the integration of existing certification categories
- Allows progressive adaptation of categories to project-specific objectives
- in addition to the assessment of "visible" elements, "non-visible" aspects, for example, of uses and interactions, can also be considered in terms of design sustainability
- Can be used as a monitoring tool within transformation processes raising transparency and cooperation awareness

The approach is low-threshold and does not require external audits. This reduces time and costs and makes it suitable for smaller projects and for representatives of municipalities, property developers, and infrastructure developers. The AD Evaluator concept presented here allows the level of detail to be refined as required, depending on the planning documents available, and the complexity of the simulations and forecast calculations to be increased step-by-step, without making major changes to the basic system.

The management of existing criteria of the different labelling and certification systems in a transparent way has proved to be very challenging. Due to the often poor documentation of the criteria, the need to translate these criteria into concrete planning measures and the need for specific project information does not allow automated criteria collection. The analysis of criteria of the most important certification system in Austria (ÖGNI, *klimaaktiv* building standard) has shown the need for a clear, temporal, spatial (including to scale) and thematic delimitation of the criteria, which must be documented in a comprehensible manner.

Integrating SDMs into assessment processes to dynamically link the interdependencies between assessment criteria and to allow the estimation of impacts of measures within automated processes needs to be further investigated. The use of SDMs in the current conceptual state of the method is the biggest limitation for practical application: The SDM used in this use case was too simple to be able to make concrete statements about the projects analyzed. More in-depth research and development is needed to find the right level of refinement of the SDM in order to derive concrete interactions between project activities and characteristics for sustainability assessment. More detailed SDMs are required, but it is important to find the right balance between the complexity of the models and their applicability in participatory and cooperative planning and decision-making processes. The case study analysis shows the need to further iteratively test the procedures with changing and, ideally, interdisciplinary planning actors for a broad bandwidth of application areas.

7. Outlook

The technical and content-related requirements for municipalities to integrate a wide range of sectoral concepts into their strategic planning are very high. In future, the proposed AD Evaluator should make it possible to assess interactions and evaluate different planning decisions against municipal objectives.

The proof-of-concept implementation of the AD Evaluator will be programmed in Python and thus can be implemented transparently in a free development environment. This enables continuous methodological and content-related improvement through the expansion and refinement of assessment criteria, based on new research findings and standardization knowledge. The development in a separate environment will also enable versatile connection options to existing assessment and analysis tools (e.g., existing certifications, test procedures), which will contribute to the expansion of the method set and to a better comparison of the assessment results. Necessary and useful functionalities are: (1) realization of the checklists and questionnaires in the form of dynamic digital forms or outputs; (2) saving and loading of ready-made activity and property lists; and (3) saving and loading ready-made policy objectives/goals.

The application of the tool will initially be tested in research projects and collaborations to make it suitable for strategic planning instruments in municipal planning.

Acknowledgments
The authors acknowledge TU Wien Bibliothek for financial support through its Open Access Funding Program.

Funding
Publication of this article in open access was made possible through the institutional membership agreement between TU Wien and Cogitatio Press.

Conflict of Interests
The authors declare no conflict of interests.

Data Availability
The research data can be provided on request.

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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Urban Planning
2025 • Volume 10 • Article 9647
https://doi.org/10.17645/up.9647

ARTICLE

Open Access Journal

Urban Transition Toward Environmental Sustainability: Instrumentation and Institutionalization of Co-Creation

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Submitted: 18 November 2024 **Accepted:** 27 April 2025 **Published:** 29 July 2025

Issue: This article is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

The transition in cities toward environmental sustainability requires transforming urban subsystems such as energy, transport, and waste infrastructure. Based on the frameworks of strategic spatial planning (SSP) and urban transition management (UTM), the urban transition is conceptualized as a long-term process in which stakeholders co-create a vision and a strategic plan, which is subsequently implemented in multiple relatively short-term projects transforming these urban subsystems. While co-creation is emerging in urban planning, ambiguity remains regarding the development and use of co-creation instruments in transforming urban subsystems. This article therefore has two aims: first, to develop a typology of co-creation instruments for urban transition planning and management; and second, to examine the institutionalization of their development and use. The article follows an iterative inductive-deductive search method to make an inventory of instruments, after which four main types are identified: participatory planning and communication tools, expert planning support systems, urban living labs, and virtual transformation labs. Several challenges in using these instruments are identified, including the need to acquire governance and digital skills, and to keep tools and data up to date. This article subsequently examines the capabilities that need to be institutionalized to support the use and development of these instruments across multiple projects. Capabilities needed are stakeholder engagement and collaborative governance, the participatory design and updating of digital tools, maintenance of urban subsystem and city development models, definition of transition scenarios and experiments, and interpretation of (simulation) results. Additional capabilities are needed to manage the project portfolio and facilitate learning within and across projects. Ultimately, a "Transition Planning Office" is proposed to institutionalize these capabilities and, by doing so, to complement UTM's focus on independent vision and agenda formulation with sustained involvement in

long-term planning, and to support SSP's call for more strategic urban planning through project portfolio management and instrument use and development.

Keywords
co-creation; environmental sustainability; institutionalization; instrumentation; living lab; planning support system; strategic spatial planning; urban transformation lab; urban transition management

1. Introduction

Many cities around the world are engaged in the transition toward environmental sustainability (see e.g., the Global Covenant of Mayors), notably aiming for low greenhouse gas emissions, low energy consumption, clean transport options, adequate waste management, green building practices, and so forth. This urban transition is a long-term, complex process fraught with uncertainty in which urban subsystems such as infrastructure (e.g., energy, transport, waste), the built environment, and the green-blue ecological network are to be transformed to meet sustainability targets. However, most of these urban subsystems rely on costly infrastructure, capital goods, and complementary technologies, with entrenched use and support by institutions, which together cause a "carbon lock-in" (see e.g., Seto et al., 2016). *Incremental* innovations of the *existing* system generally do not suffice, and instead, a *radical* change of the system is required (Loorbach, 2022). Mitigation of and adaptation to climate change need to be integrated into urban design, land use, and urban planning praxis (Bai et al., 2021; Raven et al., 2018). This may also require changes to regulations, institutions, and public services to promote sustainable consumption and economic activities (Keivani, 2009; Talen, 2012). This radical change needs to be proactively governed (Wittmayer & Loorbach, 2016) by engaging the diverse set of stakeholders (e.g., urban planners, policymakers, public utility providers, local communities, construction companies) to co-create solutions to local particularities and to find trade-offs between conflicting interests. This resonates with planning theorists' calls for progressive participation (Healey, 2020) and transforming traditional planning to facilitate co-creation by engaging a broad range of actors (Albrechts, 2013).

Despite the increasing attention on co-creation, there is still considerable ambiguity (Brandsen & Honingh, 2018) regarding its operationalization in urban transitions. Contributing to this is the fragmented evolution of conceptual frameworks, the rapid emergence of a variety of instruments, and a lack of clarity on the role of urban planners and other stakeholders therein. As a conceptual basis for examining co-creation activities in urban transition, this article synthesizes two conceptual frameworks that extend beyond the traditional master plan and zoning regulations and redefine the role of expert planning professionals in this process. First, strategic spatial planning (SSP; Albrechts, 2004, 2013, 2015) integrates long-term vision formulation and short-term change projects with adaptive learning on both vision and operational project goals. Second, urban transition management (UTM) promotes the establishment of a transition team of change agents to co-create an agenda to develop radically different urban subsystems (Frantzeskaki, 2022; Frantzeskaki et al., 2018; Nevens et al., 2013; Roorda et al., 2014; Wittmayer & Loorbach, 2016). While SSP seeks to reform existing practices and instruments toward strategic, stakeholder-oriented planning, UTM is deliberately placed outside of existing urban planning and does not prescribe methods or instruments for the long-term management of individual projects or the portfolio thereof (see Wolfram, 2018, p. 111). In synthesis, the urban transition is perceived as a long-term process driven by a shared vision for the future city, whereby this vision is realized through multiple, relatively short-term, co-created projects that transform urban subsystems. The tools, methods, and approaches for the co-creation of the urban transition process continue to evolve with the rise of new planning paradigms, theoretical conceptualizations, methodologies, data availability, and technical advancements. Not only are traditional planning tools being extended with new sustainability criteria and used in participatory planning, but also new instruments, such as living labs, digital twins, and city development simulations, are being developed. Moreover, applications of online platforms for participation, data-intensive analytical tools, and digital decision support systems are on the rise, also in urban transition planning. However, there is currently neither a comprehensive overview of instruments nor a clear understanding of how to adequately develop and use them in practice. As such, the article has two aims: to develop a typology of co-creation instruments and to examine the institutionalization of the development and use of these instruments in urban transition planning and management. First, the typology is developed by making an inventory of instruments according to an iterative inductive-deductive approach (see Mayring, 2000) and subsequently classifying and clustering them into types. Hereby, the instruments are assessed on three dimensions: whether they focus primarily on qualitative information exchange or rather quantitative data analysis using digital tools; whether they are expert-led or rather follow a participatory or collaborative governance approach; and whether they support short-term decision-making or rather long-term strategic planning, experimentation, and learning. Based on this classification, four distinct types of instruments for urban transition are discerned: participatory planning and communication platforms, expert planning support systems, urban living labs, and virtual transformation labs. In addition, the article identifies specific challenges in using digital co-creation tools, particularly in planning support systems and virtual transformation labs. Second, given the long horizon and the multiple projects in which co-creation instruments are to be used, the article examines the institutionalization of their development and use. Urban transition planning requires building capabilities not only for stakeholder engagement for vision formulation and strategic planning, but also for the participatory design, maintenance, and use of urban subsystem and city (development) models, as well as the analysis of (simulation) data. Moreover, given the rapid evolution of co-creation initiatives and instruments, planners need capabilities to monitor and learn within and across projects (possibly in other cities) as well as to manage the overall portfolio of transition projects. This article thus contributes an operational perspective on co-creation instrumentation and institutionalization to the existing literature on urban transition and planning theory. While not a primary aim, the article also proposes a "Transition Planning Office" (TPO) as the institutionalization of these capabilities. The TPO complements the integration of strategic planning proposed by SSP and the deliberately independent transition arena proposed by UTM.

The structure of the remainder of the article is as follows. Section 2 provides the conceptual framework for the co-creation of urban transition and builds upon the SSP and UTM approaches to outline the purpose and challenges of instrumentation and institutionalization. Section 3 presents the typology of instruments, explains the methodology used to develop this typology, and discusses challenges in the implementation and adaptation of these instruments. Section 4 discusses the institutionalization of transition planning and management, focusing on capabilities required for stakeholder governance and using instruments within and across the range of urban subsystem transformation projects. Section 5 provides conclusions and insights into the instrumentation and institutionalization of co-creating transition planning and management.

2. Conceptual Framework

2.1. Co-Creation of the Urban Transition to Environmental Sustainability

As described above, urban subsystems may be in a carbon lock-in (cf. Seto et al., 2016), such that their transformation to become environmentally sustainable needs to be proactively governed (Hölscher, 2018; Loorbach, 2022; Wittmayer & Loorbach, 2016) and may require changes not only to infrastructure, but also to regulations, institutions, and public services (Keivani, 2009; Talen, 2012). However, alternative transformations may exist. For instance, air pollution from transportation can be reduced by introducing congestion pricing during peak hours, implementing ride-sharing systems, enhancing public transportation, restructuring the road network, and making cities walkable. Similarly, CO_2 emissions from energy consumption can be reduced through energy-saving campaigns, subsidizing smart appliances, switching to green electricity in public buildings, promoting the purchase of solar panels, subsidizing building insulation, and imposing stricter building standards. Which options are feasible and preferred may depend on local circumstances, stakeholder capabilities and interests, as well as interrelations between transition solutions.

The diversity of stakeholders (e.g., policymakers, public utility providers, local communities, companies, investors) and their different interests make the transformation of urban subsystems a potential source of conflicts. Breaking out of the carbon lock-in therefore requires the co-creation of transformative solutions with trade-offs that are acceptable to these stakeholders. Arguably, the government has both the mandate and responsibility to engage these stakeholders and facilitate this co-creation process. This is also in line with the broader trend toward greater involvement of stakeholders in governmental decisions in general, and of stakeholder engagement and participatory governance in urban planning in particular (Healey, 2020). Stakeholders are not merely involved for tokenism or legitimation but are genuinely delegated decision-making power (Albrechts, 2013; Fugini et al., 2016; Leino & Puumala, 2021). Co-creation thereby leads to solutions that are neither imposed by expert decision-makers (top-down) nor driven by interest groups, citizens, or powerful stakeholders (bottom-up) but rather by engaging a variety of stakeholders across hierarchical relationships (Leino & Puumala, 2021).

However, in general, the concept and instrumentation of co-creation are still ambiguous and emerging (see e.g., Brandsen & Honingh, 2018). The understanding of what co-creation is (and could be) in the context of the urban transition is rapidly developing with (a) the conceptions of the urban transition in terms of goals, phases, and tasks, (b) the various perspectives on the transition-related activities and the role of various institutions therein (see SSP and UTM), and (c) the variety of operational instruments, methods, and approaches.

As discussed in the following subsections, the urban transition is seen as a long-term process driven by a co-created vision and development agenda, notably featuring relatively short-term projects that transform urban subsystems (infrastructures, utilities, services, built environment) aligned with that vision. As such, co-creation is understood as a governance approach in which an "urban transition agent" collaborates with stakeholders to formulate a shared vision and roadmap for urban developments. However, over time, new challenges and opportunities may arise, and specific developments may need to be deferred or adjusted. Given its inherent complexity and uncertainty, the transition process cannot be tightly planned but instead features experimentation, monitoring, learning, and adaptation both within and across projects. This requires alternative governance structures not only for the initial formulation of the vision and agenda but also to facilitate the long-term engagement of stakeholders in co-creation activities (see e.g., Mahmoud et al., 2021). Thus, in the context of urban transition, co-creation is de facto characterized by the instruments applied to a range of tasks and the institutionalization of the involvement of stakeholders. The next subsections discuss key conceptual frameworks for planning and managing urban transformation, followed by the outlines of the instrumentation and institutionalization of co-creation within these frameworks.

2.2. SSP for Sustainability

Urban planning has evolved from being an authoritative, regulatory approach with institutionalized, government-led urban development practices to an approach that uses stakeholder engagement, participation instruments, and various governance modes (Faludi, 1973; Healey, 2020). SSP emerged as one of the responses to the dominant expert-led, top-down approaches. As Albrechts (2013, p. 52) summarizes:

> Strategic spatial planning is looked upon as a transformative and integrative public sector-led, but co-productive, socio-spatial process through which visions or frames of reference, the justification for coherent actions, and the means for implementation are produced that shape, frame and reframe what a place is and what it might become (Albrechts, 2010: 1117; Motte, 2006; Oosterlynck et al., 2011; Van den Broeck et al., 2010).

SSP revolves around participatory involvement of empowered citizens and a broader set of stakeholders (firms, environmental groups, consultants) and translating these visions into short-term actions (Albrechts, 2004). Moreover, rather than merely soliciting citizens' opinions to subsequently have professionals do the planning and projects, these citizens are involved in "agenda setting, problem formulation, the shaping of the content of policies, plans and projects and the delivery as well" (Albrechts, 2013, p. 53). SSP thereby challenges existing relationships and rather seeks to empower and include innovative change agents in an adaptive, co-creation process (Albrechts, 2013, 2015). In SSP, a shared, long-term vision is co-created and subsequently implemented in short-term projects, adapting these in continuous learning while involving stakeholders to mobilize networks and capabilities.

Urban development has traditionally been (and generally still is) regulated through master plans and zoning regulations, and even though these may, in some cases, cater to sustainability goals (Jepson & Haines, 2014), transforming existing energy and transport infrastructure to meet these goals would typically necessitate radical redevelopment. In practice, urban planning does use methods and systems to reform land use and energy and transportation infrastructure, albeit typically not from a sustainability transition perspective (Walsh, 2018). Generally, the planning of urban subsystems is path-dependent rather than path-breaking (see e.g., Malekpour et al., 2015). Although SSP should be integrated into regular urban planning approaches (Wolfram, 2018, p. 111), it is intended to be complementary to, rather than a substitute for, the common planning tools such as land use, master planning, or zoning.

2.3. UTM

Unlike SSP, UTM explicitly starts from the premise that radical change is needed and that the ideas for this are best formulated in a "safe space" sheltered from the influence of the actors within the unsustainable pre-existing system. It advocates bringing together a deliberately broad variety of "frontrunners" to develop a shared understanding of the urban transition challenges, formulate a collective, long-term vision for the city, and translate this into flexible pathways with short-term active experimentation and learning (Wittmayer & Loorbach, 2016; Wittmayer et al., 2018). As described in detail in Roorda et al. (2014), an initiating agent kickstarts the formation of a "transition team." This team drives the management process, analyzes the urban subsystems to be transformed, and conducts a stakeholder analysis to invite change agents in a "transition arena." This transition arena is a small, diverse group of change agents from various backgrounds (e.g., municipality, companies, research institutes, citizens) and domains (e.g., energy, transport). Over the course of several meetings, the arena participants formulate the transition challenge, problem framing, and visions for the future. Using these visions, arena participants engage in backcasting methods to define possible pathways to realize the visionary image (such as a roadmap of actionable goals towards transforming the city). Transition experiments are used to explore and assess the viability of radical changes to resolve transition challenges. The action plans and their associated transition experiments used to realize long-term visions and pathways are documented in the transition agenda. This agenda encompasses "a strategic perspective—a transition narrative—that can be used as an anchor point for new initiatives and policy" (Roorda et al., 2014, p. 32). This agenda is (merely) a means to engage the wider audience and influence the agenda of others, e.g., by organizing networking events, by seeking publicity, by integrating elements into existing processes, or by introducing transition concepts and practices within municipal organizations.

Since the agenda merely sets the direction for the long term and guides actions in the short term, the next step would be to initiate transition projects. Such projects hinge on actors that gather the required competences, funding, and resources to operationalize the ideas in the agenda. This is a "working group" of actors responsible for project management and involving companies and policymakers. Moreover, a coordinator is required to facilitate ongoing engagement and reflection among actors involved in the transition process.

Despite the name of the approach, transition management does not prescribe methods or instruments for the *long-term* management of single initiatives, let alone the portfolio of transition projects. Indeed, the transition arena is just a temporary, short-term process at the front-end of the transition, and is foreseen to cease to exist after formulating the agenda and engaging the wider audience. Nonetheless, there is a lack of clarity about the actual institutionalization of the long-term transition activities. In addition, at some point, moving forward with changes to a socio-technical system or public service becomes a matter of design, engineering, project planning, procurement, and execution. The room for adaptation and co-creation tends to diminish. So, it seems that, to a certain extent, short- and mid-term urban planning methods and activities are expected to exist side-by-side with the long-term transition perspective.

2.4. Instrumentation and Institutionalization of Co-Creation in Urban Transitions

Both the long-term urban development vision and agenda as well as the portfolio of relatively short-term projects transforming urban subsystems are co-created. Each project is a transition challenge with a variety of solutions to consider. Currently, urban planners take the long-term master plan, land development plan, and zoning regulation as guideline. So, arguably, urban planners lack a toolkit of instruments to research, develop, and implement transition solutions in actual urban planning practice (cf. van de Ven et al., 2016). In part, this may be due to an inherent tension between long-term, "vision-pulled" transition processes that emphasize experimentation and reflection and the relatively short-term urban planning and design projects that merely extrapolate from existing developments. Clearly, striving for the materialization of plans is at odds with keeping options open and postponing changes that are costly to reverse. So, this experimentation and analysis occurs prior to the planning, requiring additional instruments and arrangements. Neither core UTM nor SSP literature is explicit about instrumentation for analysis and decision-making. Moreover, core UTM literature refrains from discussing the institutionalization of front-end vision formulation, long-term process management, or short-term practical planning activities.

Despite their commonalities, both SSP and UTM have their own instrumentation and institutionalization requirements. Notably, UTM requires qualitative support for radical innovation, roadmap backcasting with short-term experimentation, monitoring, learning, as well as adopting grassroots initiatives. In contrast, since SSP is integrated into existing planning practices, it may have more use for long-term data and extrapolated trends and means for adjusting existing policy programs and zoning regulations. Moreover, co-creation with stakeholders far beyond regular planning commissions is prominent in both, so instruments and practices need to be developed in any case. Either way, given its novelty, complexity, and scale, the urban planning praxis has to develop "competences for designing transition management processes in cities and engaging with multidisciplinary knowledge in solution-seeking processes" (Frantzeskaki et al., 2018). Urban planning offices need to learn how to set up, develop, plan, and ultimately manage the execution of these transition projects. In the following two sections, both instrumentation and institutionalization for co-created transition are examined in detail.

3. Instrumentation of Transition Co-Creation

Over the past decades, the toolkit of instruments in urban planning has been evolving, notably in response to changes in aspirations, considerations, and responsibilities in planning theory (Allmendinger & Tewdwr-Jones, 2001), the rise and fall of movements (Garde, 2020), and the emergence of urban ideals such as the eco-city, walkable city, 15-minute city, etc. Moreover, new instruments have been developed leveraging digital technology and its modeling and decision-support capabilities, such as the smart city and digital twin city (see e.g., Batty, 2001; Silva, 2010). In addition, there has been a rise in online platforms for citizen participation in general (see Ragi Eis Mendonca & De la Llata, 2023; Rodriguez Müller, 2022) and urban planning in particular (see e.g., Abdalla et al., 2016; Ertiö, 2015; Falco & Kleinhans, 2018; Giannoumis & Joneja, 2022; Hovik et al., 2022). However, as discussed in the previous section, the co-creation of urban transformation requires additional instruments, particularly for at least two distinct process steps. Firstly, there is co-creation in the formulation of visions and the agenda to develop the envisioned city. The latter could be a roadmap of actionable goals and tasks based on backcasting, expert assessments, or analysis with a (computational) city development model. Secondly, there is co-creation of a variety of projects to transform urban subsystems (energy, waste, transport, blue-green ecological network), each of which requires analysis, decision-making, practical planning, and actual construction. It is conceivable that certain parts of the city development analysis in the first step are deferred to the more incremental, piecewise analysis in the second step. Particularly in SSP, the agenda readily sets outlines for activities for stakeholders in planning change. In UTM, the agenda outlines radical changes formulated by change agents, but leaves room for experimentation and learning, and thus needs to facilitate processes to do so. So, arguably, the toolkit for urban transition requires instruments for participatory vision formulation, analysis of the impacts of changes, co-creation of individual transformation projects involving different sets of stakeholders, and, ultimately, specification and execution of plans with room for experimentation and learning. This section takes stock of the current toolkit of instruments for these process steps, specifically aiming to distinguish "types" of instruments based on their properties.

3.1. Three-Dimensional Spectrum for Instrument Classification

The selection and subsequent classification of instruments should be based on their (potential) use throughout the urban transition process, particularly in co-creating (the vision and plans for) projects and their implementation. Notable efforts have been made to map instruments to the various phases in the (short-term) urban planning process. Tasks and responsibilities in the planning and development process are often structured into consecutive phases (see e.g., Hopkins, 2001, p. 191), in each of which different instruments are used (see e.g., Siems, 2023, p. 53). Generally, a planning process consists of the following phases: (a) system analysis (using instruments for information and data collection, statistical analysis, and mapping), (b) collaborative goal setting (using instruments for brainstorming, preference analysis, and dealing with trade-offs between interests), (c) making action plans (e.g., using what-if analysis, cost-benefit analysis, roadmapping), and (4) project implementation and management. For long-term transition processes consisting of a multitude of subsystem transformation projects, activities can generally be separated into two broad phases: a phase of vision formulation and strategic planning followed by a phase of implementing a series of projects. In UTM, these projects take the form of experiments with monitoring, reflection, and provisions for adaptation. As such, one of the key dimensions of interest is whether instruments are of use in short-term urban transformation projects or rather support long-term planning, experimentation, or city development concerned with multiple short-term projects. Note that whether tools are applied over a longer time horizon or not has implications for the design and maintenance of these instruments, as well as for procedures and practices for updates based on intermediate developments.

In addition, there is ample literature on developments in instruments for two more dimensions. Particularly noteworthy is the increase in the use of digital tools (see e.g., Lieven et al., 2021; Staffans et al., 2020). This trend highlights the relevance of positioning instruments along a methodological-analytical dimension, ranging from low-tech tools for collecting, exchanging, and analyzing qualitative information and stakeholder perspectives to high-tech tools for quantitative, data-rich analysis, simulation, or optimization.

Moreover, planning instruments changed substantially during the "communicative turn," when stakeholder engagement, participation, and other governance modes came into focus (Faludi, 1973; Healey, 2020). Thus, the third dimension pertains to the governance mode of instruments, which ranges from being applied by experts for top-down decisions (as in rational-comprehensive planning, for example) to involving a variety of stakeholders such as urban planners, municipal governments, residents, utility companies, and construction firms in co-creation. There is also bottom-up, grassroots-driven change (e.g., tactical urbanism, transition towns), but strictly speaking, this is not an instrument that can be actively wielded. However, participants in such grassroots movements could be invited to join the transition arena. Moreover, transition planners may cultivate such movements and adopt successful initiatives for wider co-creative application.

In conclusion, instruments for co-creating urban transition can be positioned within a three-dimensional spectrum: (a) from qualitative, conceptual, data-extensive, low-tech instruments to quantitative, data-intensive, high-tech instruments; (b) from hierarchical, expert-driven planning to collaborative planning with stakeholder engagement; and (c) from short-term, singular projects to long-term transition agendas.

3.2. Methodology for Instrument Identification, Characterization, and Typology Formulation

The first aim of this article is to formulate a typology of instruments that are either already used or suitable for use in the co-creation of the urban transition. However, finding and identifying these instruments is challenging because the conceptions of the transition process, the planning of urban transition projects, and the usage of co-creation instruments are all relatively recent and therefore possibly insufficiently reported. Consequently, instrument designations and terms used vary across disciplines and stakeholders. Moreover, instruments differ substantially in nature (ranging from digital tools to participation methods to governance frameworks), and many exist that have not yet been applied in urban transition planning and management. City planners, consulting agencies, applied research institutes, and other actors are engaged in developing new instruments, so the entire toolkit, its applications, and associated keywords continue to evolve. Consequently, what one is searching for changes with insights from what is being found.

Given these challenges, this article adopts a structured exploratory snowballing approach based on selected principles of qualitative content analysis, particularly iterative deduction-induction, content interpretation (for keyword selection), and progressive typology development (Kluge, 2000; Mayring, 2000). The approach consists of two stages: iterative search and consolidation. The search alternates between a deductive step, in which keywords and sources are used to identify new instruments, and an inductive step, in which content analysis of instrument descriptions expands the keywords and sources used next. The keywords include both designations of actual instruments as well as generic properties that describe their characteristics and applications. In conjunction with the expansion of the set of instruments and progress in understanding their properties and applications, the (conceptual basis for the) selection and typology of instruments is also gradually refined (see notably Kluge, 2000, on integrating typology discovery in qualitative content analysis). Ultimately, there is a consolidation of the types of instruments. The methodology for instrument search and type identification is depicted in Figure 1 and described below in detail.

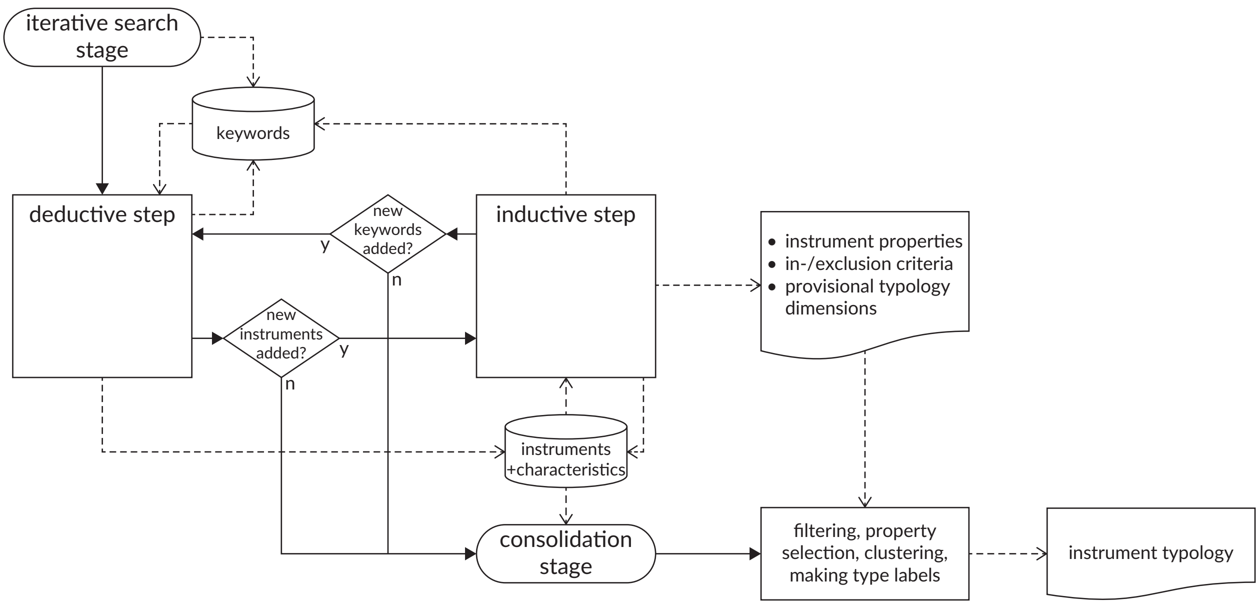

Figure 1. Search stages and steps in the identification of instruments and typology formulation.

The iterative search for instruments alternates between deductive and inductive steps. In the deductive step, the search is conducted using (combinations of) keywords associated with co-creation, governance methods, digital tools, conceptual approaches, etc., looking for instruments that are or may be used in urban transition. This is aimed at creating a broad, diverse inventory. Initially, the list of keywords for search is based on the prior literature study. The search commenced in several directions: one on communication with and participation of stakeholders (using keywords such as "participat*," "engag*"), one on digital tools (e.g., "digital planning," "digital platform," "GIS"), and one on governance forms (e.g., "governance," "expert," "grassroots"). In general, these keywords were combined with keywords on the transition itself (e.g., "sustainab*," "green," "environment*"), and spatial context (e.g., "urban," "city," "town," "metropol*," "region*"). One general and two academic literature search engines (Scopus, Google Scholar) were used. Initially, primarily academic peer-reviewed literature was searched, but over iterations, this got expanded with conference proceedings (notably for digital tools), gray literature (consulting reports, white papers), and websites of (networks of) municipalities, (applied) research institutes, etc. Each discovered instrument was recorded in a database for further in-depth inquiry.

In the inductive step, specific designations of instruments (e.g., "citizen participation," "living lab," "DIPAS") are used for in-depth search to add a description, references to academic literature, and links to applications to the records in the database (occasionally also found in gray literature, websites of research institutes or municipalities, and so on). Content analysis of descriptions of the instruments and applications occasionally results in new instruments to be added for further in-depth analysis but also alternative keywords or new sources. In-depth search may also lead to merging records of highly similar instruments. As part of the inductive step, specific values were assigned to various instrument properties, such as Arnstein's ladder of participation, actors involved (the organizer and main participants), frequency of use, time interval of expected impact, and the direction, purpose, and type of information exchange. For most of these properties, serious attempts were made to characterize all instruments so that these properties could be used in devising a typology. After each inductive step of in-depth analysis of additional instruments, the authors discussed properties of instruments (and whether to add new properties for potential use in the typology later), instrument in- and exclusion criteria, and revision of inductive search directions, sources, and keywords.

This iterative process culminated in the identification and characterization of a wide variety of instruments, ranging from generic communication and voting tools, to early-stage participatory vision formulation and advanced decision-support tools for urban subsystem design and project planning. The iterative search stopped when newly identified instruments were mere variations or applications of those already in the dataset (cf. Saunders et al., 2018). At that point, the aim of finding the main *types* of instruments was presumably attained.

The subsequent consolidation stage focused on finalizing the instrument typology by first filtering instruments and then selecting properties for clustering into types. After the search stage, the dataset still contained numerous instruments recorded for further in-depth analysis, but for which limited evidence of active use for transition planning or management was found (e.g., "citizen science," "hackathon"). The filtering kept only instruments that can be used for formulating visions (e.g., "town hall meetings"), analysis of city developments (e.g., "using models," "expert panels"), setting actionable goals and planning tasks (e.g., "backcasting," "roadmapping"), or running projects (e.g., "living labs"). Since properties added during the iterative phase were not equally relevant, a subset was selected for clustering instruments into types. Several different subsets of properties were already considered for clustering during the iterative stage. However, ultimately, the three key dimensions discussed in the previous section emerged as the basis for clustering, with one based on theory (time horizon) and the other two reflecting observed trends in instrument development (participation, digitalization).

3.3. Types of Instruments

The inventory of instruments led to the following four distinct types in the three-dimensional spectrum (see Figure 2).

3.3.1. Participatory Planning and Communication Platforms

The most generic type is that of communication and participation instruments used for information exchange, soliciting feedback, and collaboration in the formulation of strategies and plans without using computer models, advanced data-analytical means, or any need for advanced digital skills or expert domain knowledge. At its core, urban planning often has a regulatory role in which a planning or zoning commission (typically composed of city council members, officials, and sometimes advisors) reviews building proposals to ensure alignment with zoning, environmental guidelines, and community objectives as outlined in master plans and development strategies. Formulation and regulation used to be the responsibility of urban city planners and experts. However, ever since the "communicative turn," there has been a more explicit focus on collaboration and participation in urban planning (Healey, 2020). Prompted by actors seeking to change land use, by developments such as demographic or economic growth or decline, or following a broader call for mitigation and adaptation to climate change, urban planners may involve a wider set of stakeholders in the formulation of the urban development vision, strategies, regulation, and plans (see e.g., Hopkins, 2001). To this end, there is a large toolkit of participation instruments particularly suitable for making an inventory of transition challenges or formulating visions at the outset (e.g., focus groups, surveys, town hall meetings, citizens' assemblies, deliberative mini-publics, citizen councils/panels, planning cells, and community forums). On a variety of such participation formats, see Nanz and Fritsche (2012) and OECD (2020). Already actively used in later stages of urban redevelopment projects, city planners also have a toolkit for engagement with the general public and public communication tools (e.g., interactive exhibits, billboards, outdoor photo exhibits, scaffolding scrims). More recently, tools for online or offline digital participation (with labels such as e-participation or digital democracy) have emerged that seek to engage a larger and possibly broader group of citizens in policymaking and co-creation of public services (Ragi Eis Mendonca & De la Llata, 2023; Rodriguez Müller, 2022). Also for participation in urban planning, there are various online platforms (Abdalla et al., 2016; Giannoumis & Joneja, 2022; Hovik et al., 2022), offline digital tools, and apps (Ertiö, 2015; Falco & Kleinhans, 2018). There are numerous examples of how digital city platforms are used in participatory urban development and design (see e.g., Galassi et al., 2021; Giannoumis & Joneja, 2022; Lieven et al., 2021; Noennig et al., 2023). Given the novelty of such tools, the formulation of guidelines for online participation in urban planning is due (Afzalan & Muller, 2018; Hofmann et al., 2020).

Generally, participation instruments differ in the degree of engagement and actual decision-making power of participants (Arnstein, 1969). Some of the tools seem to be more suitable for consultation than genuine co-creation processes with community members and other stakeholders. In contrast, UTM focuses on instruments for co-creation with a deliberately picked set of *change agents* (e.g., roadmapping, formulation of a transition vision and agenda in the transition arena, collaborative policy formulation in a policy lab). Central in transition management is also the element of experimentation and learning in a real-world setting which forms the basis for the second type of co-creation tool.

3.3.2. Urban Living Labs

There are several instruments for medium-term, real-world experimentation and co-creation, such as Reallabor (Schäpke et al., 2017), Urban Living Lab (Aernouts et al., 2023; Bulkeley et al., 2016; Mahmoud et al., 2021; Voytenko et al., 2016), Urban Transition Lab (Nevens et al., 2013), and Community Design Charrettes (Lennertz & Lutzenhiser, 2017; Roggema, 2014). We will use the term "urban living lab" as the general term to refer to this kind of instrument. Such urban living labs are concerned with ongoing participation, experimentation, and learning to find and test local solutions to societal challenges in real-life settings (Bulkeley et al., 2016; Nesti, 2018; Voytenko et al., 2016). However, urban living labs differ substantially in their goals and forms of the co-creation process (Nesti, 2018; Puerari et al., 2018). Moreover, some initiatives, such as transition towns (Connors & McDonald, 2011), are arguably a form of living lab, though arising from a grassroots movement or a bottom-up community-led or corporate frontrunner-led initiative, rather than a top-down initiative of researchers or urban planners. Given the open concept of urban living labs and the extended time interval over which such labs may persist, participants may also use other types of instruments (see e.g., the mapping of instruments to elements of the urban transition lab in Nevens et al., 2013, p. 116). This gives rise to hybrid forms, such as living labs using digital co-creation tools (Lieven et al., 2021; Mačiulienė & Skaržauskienė, 2020). However, practically, whenever such local, experimental, and temporary tactical urban development initiatives are considered successful, further diffusion and implementation would require at some point in time more expert-driven urban planning, adjustments to regulations, and actual construction project management. So, experimental co-creation leads the way for professional urban planning, which is rather the next type of instrument.

3.3.3. Expert Planning Support Systems

There is a toolkit used by urban planning professionals for short- to mid-term urban planning and design. The more traditional instruments of land use, master planning, and zoning ordinances are still used, albeit often also modernized. Planners use not only generic digital tools (e.g., QGIS, SketchUp, digital land use maps), but also data-intensive digital tools and systems for planning support (Geertman & Stillwell, 2004, 2009). Over the last few decades, these tools have advanced significantly, driven by developments in technology, data science, and the increasing availability of (real-time) data. A prominent advancement is the integration of GIS-based digital twins in tools for transportation and transit planning (e.g., TransCAD, TBEST, Hastus, PTV Visum), risk and resilience assessment (e.g., flood, heat, or disaster scenarios), and urban development simulations (e.g., UrbanSim, ArcGIS CityEngine). Modeling the urban subsystems typically requires the input of trends, scenarios, or models of demographic development, travel behavior, citizen preferences, etc. (see e.g., Landis, 2012), using, for example, agent-based models (Huynh et al., 2015; Namazi-Rad et al., 2017). Such tools support decisions on land use, locations for amenities, provision of public services, etc. Planners also have an interest in a digital *twin* model that represents *the actual state* of a focal city, sometimes even showing real-time data, such as on mobility patterns, energy consumption, etc. (see e.g., Anttiroiko, 2021; Gil, 2020). Such digital twins may even use real-time data collected in "smart cities" for operational management (e.g., of traffic flows) and computational urban planning (Douay, 2018; Geertman et al., 2019; Goodspeed et al., 2023). Such support tools can be used to identify challenges (e.g., traffic bottlenecks, heat islands), opportunities (e.g., solar irradiance), and evaluate *incremental* changes (e.g., locations of schools, small transport network changes). These features make such tools suited for communication and collaborative planning with residents, firms, and other stakeholders. That said, despite their sophistication, these tools are inherently limited when it comes to planning for long-term, transformative urban change. After all, historical or present-day data on current conditions such as mobility patterns and energy usage have limited value in projections about the city in radical transformation scenarios. Therefore, these digital twin-based support tools are suitable for studying and planning *incremental* change, but not for visionary, radical transformation. This calls for the fourth type of instrument.

3.3.4. Virtual Transformation Labs

These instruments are virtual or physical laboratories for stakeholder involvement, collaborative planning, and decision-making using digital or hybrid physical–digital city models for long-term transition planning. The dividing line between the planning support tools discussed before and the transformation laboratories for virtual city development lies in the latter's persistent focus on multi-stakeholder interaction for strategic decisions and the ability to conduct radical, virtual experiments and scenario analysis over the long term. Virtual transformation labs use a flexibly configurable digital city development model to examine the impact of changes to the city (e.g., built environment, transportation network, green-blue infrastructure), notably using simulation, with the explicit intention to evaluate deliberate, radical changes, conduct "what-if" experimentation, and support formulation of visions and strategic planning. Examples of the latter are CityScope (by MIT; Alonso et al., 2018), Cockpit for Collaborative Urban Planning (HafenCity Hamburg, Austrian Institute of Technology, MIT Media Lab), Smart Region Lab (Hochschule Luzern), and the Decision

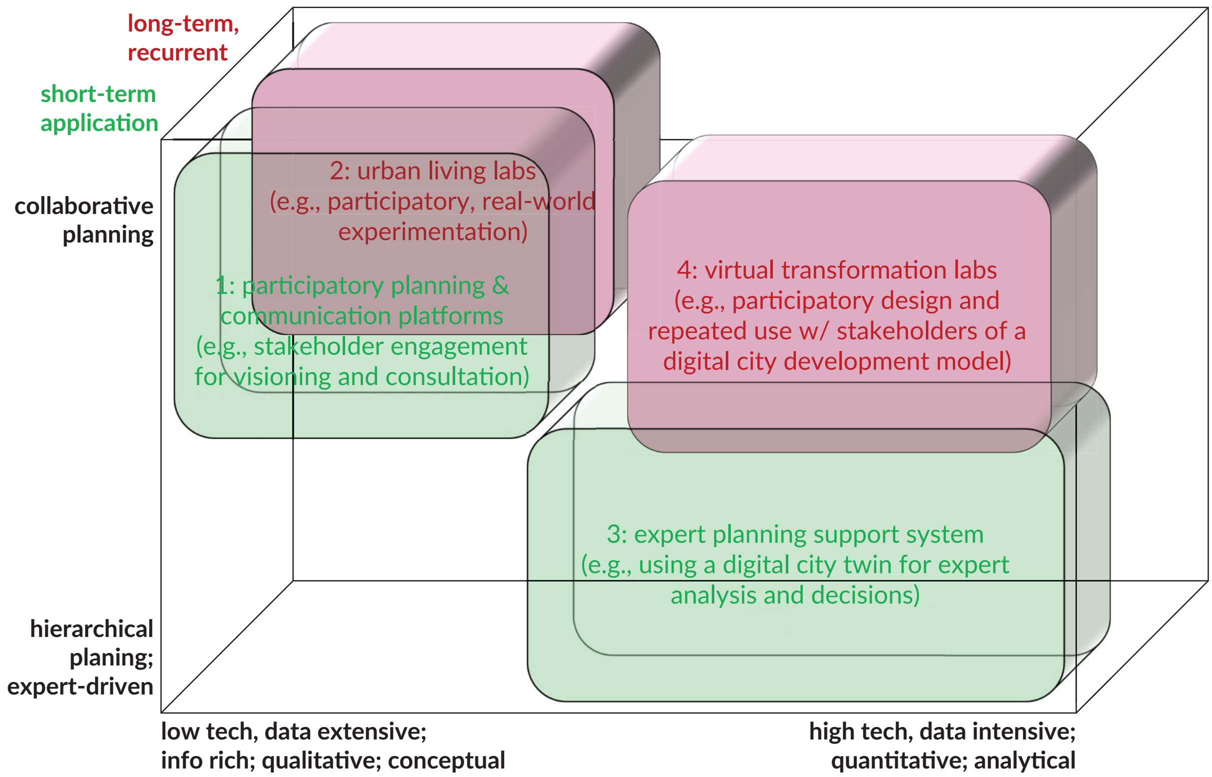

Figure 2. The four types in the three-dimensional spectrum of transition instruments.

Theater (Arizona State University). Although the technology and participation method are generic, the geographical scope, problem and system definitions, as well as building the network of change agents involved are time- and resource-intensive, so consequently mostly place-specific models and labs emerge. In these examples, the research institute, the city development model, and the main visualization platform are closely associated. Moreover, the content of the models, the interaction and interface of the visualization platform, and the use in and content of workshops are typically designed in participation with stakeholders. In the cases studied, the laboratories and underlying city models are not finished but continue to be developed for specific (applied) research projects. The development and application of these tools are therefore part of "action research." In real-world living labs, the progressive application and scaling up of experiments must be approached prudently, subject to monitoring and reflection, and with options for roll-back. In virtual laboratories, in contrast, experiments can be large-scale and radical, though their impacts are, of course, based largely on assumptions and simulations rather than observed outcomes.

3.4. Implementation Challenges of Digital Instruments

The descriptions of the four types of instruments contain indications on how they can be used in the co-creation of transition. However, the use of *digital planning support tools* (Type 3 in Figure 2) and *virtual transformation labs* (Type 4) is relatively recent. Despite the arguments in favor of the use of digital co-creation instruments, the actual implementation and application face several challenges, four of which will be discussed here.

First, there is the challenge of operationalizing the transition process. The transition is a long-term process with open-ended experimentation and complex interactions between subsystems to be transformed. Providing quantitative data and defining meaningful scenarios for analysis with digital city models is challenging, but without this, the tool has limited value. This is reminiscent of the so-called "implementation gap," i.e., the limited uptake of planning support systems despite their availability (Geertman & Stillwell, 2004, 2009), partly due to limited usefulness for strategic planning (te Brömmelstroet, 2017).

Second, there is the challenge of ensuring that the city transition model is location-specific and up-to-date. Further application is hindered by the substantial differences among cities in their transition challenges, urban subsystems, stakeholders involved, and future city visions. So, there is no one-size-fits-all template for the transition dynamics. Instead, tools, data collected, policy scenarios, and even transition management capabilities need to be tailored to such place-specificities (cf. Larbi et al., 2021). Moreover, the models and underlying data need to be updated frequently to reflect real-world developments. In addition, the city model and simulation scenarios need to be extended for new transition projects when they arise.

Third, planners are dependent on the developers to update the tools and notably underlying models. However, not uncommonly, the development of digital tools is part of academic action research of individual researchers or even research institutes. In fact, researcher-developers may well engage with the stakeholders for the specification of the digital city model and scenarios, participatory design of the interface and the tool's use cases, and have actual workshops for decision support as the final deliverable of the project. These tools may fail to meet the practical needs of planners. Moreover, for such tools, there is often no explicit intention to develop them commercially or maintain them in the future. Notable exceptions include digital participatory planning systems and laboratories associated with city or regional development institutes. Hereby, a base platform is developed over time, with smaller tools for specific research purposes built on top. However, since these need to be made location-specific, one faces the second challenge.

Fourth, using digital co-creation tools also requires a change in the role and skills of urban planners. By design, engagement with stakeholders and a focus on mid- to long-term transformation are central. On top of their regular domain knowledge, planners would need to be able to operationally define city development models, specify transition scenarios, develop skills to work with simulation software, and analyze output data. Moreover, effective use of digital tools in planning workshops requires facilitators to make thoughtful interventions to ensure appropriate tool use and balance this with contextual discussions (Pelzer et al., 2015).

Urban planners face challenges not only in implementing and using these digital instruments, but also in adopting the mindset, procedures, and practices for transition co-creation. This is discussed in more detail in the next section.

4. Institutionalization of Co-Creation of the Urban Transition

The urban transition is a long-term process in which a portfolio of relatively short-term projects transforms various urban subsystems. The previous section identified instruments planners may use for the transition planning and management. In line with observations in SSP and, to a lesser extent, UTM, this transition process may also require procedural changes to planning practices. After all, instruments may need to be updated, projects need to be monitored, learning is to be facilitated, and the project portfolio is to be managed. Surprisingly, the literature reports little on the actual institutionalization of such transition planning and management. In fact, while UTM emphasizes that the transition agenda should be anchored, e.g., by engaging and mobilizing stakeholder networks around projects (Roorda et al., 2014; Wittmayer et al., 2018), such durable anchoring is rarely reported (Hölscher, 2018, p. 385). This section discusses four activities of transition management that need to be institutionalized: (a) building capabilities and activities for stakeholder engagement, governance, and co-creation; (b) developing and updating data, tools, and city models for analysis in subsystem transformation projects; (c) building capability for and facilitating learning across projects at the city level; and (d) learning from similar projects as well as transition co-creation methods in other cities. The capabilities and their relationships are depicted in Figure 3 and explained in detail below.

4.1. Building Capabilities for Stakeholder Engagement, Governance, and Co-Creation

Both SSP and UTM advocate a change in planning praxis toward engagement with and collaboration between a diverse set of stakeholders far beyond the zoning committee. Given that the urban transition is a unique undertaking for each city, urban planners and the various stakeholders involved will (have to) develop capabilities, both for co-creation of the top-level vision, strategy, and agenda with change agents as well as for subsystem transformation projects (cf. Albrechts, 2013; Frantzeskaki et al., 2018) involving stakeholders closer to the actual construction (e.g., system experts, construction companies, affected citizens, relevant municipal departments). In both approaches, co-creation requires alternative governance structures and long-term commitment, and therefore institutionalization (see e.g., Mahmoud et al., 2021). This shift toward co-creation calls for new skills and education for urban planners (Rooij & Frank, 2016).

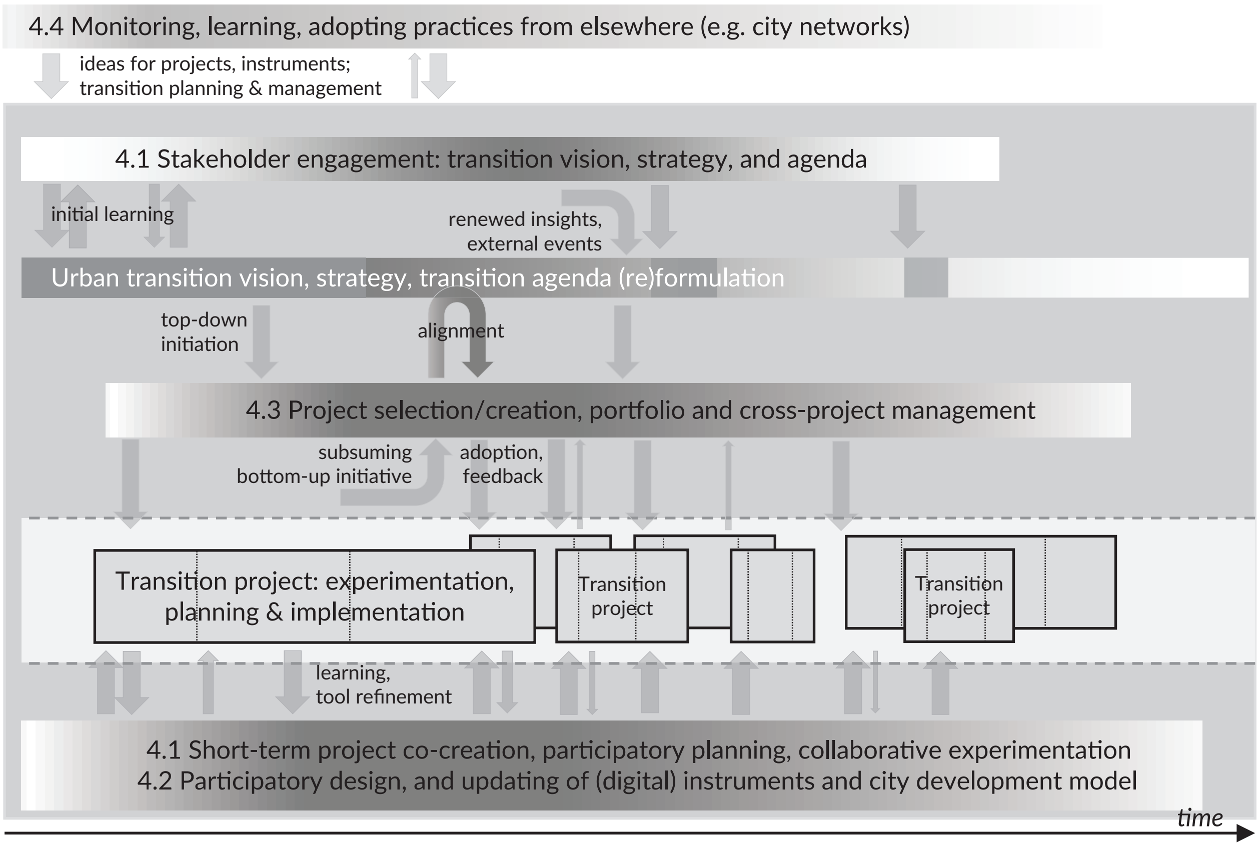

Figure 3. Schematic overview of capabilities in managing the various urban transition projects. Arrows indicate information flow between different activities for the purpose indicated by the labels. Descriptions are provided in the sections with the given numbers.

Planners must develop capabilities to navigate the different perspectives and interests of the participants, and cope with conflicts and trade-offs by creating effective compromises (cf. Albrechts, 2013).

In SSP, co-creation is to be integrated into the day-to-day planning praxis for both vision formulation as well as proactive co-creation and alignment of real-world transition projects. In this case, co-creation is institutionalized and integrated into urban planning and design, regulations for public utilities, and so on. In UTM, the transition arena is deliberately placed outside of the regular planning institutions (Wolfram, 2018, p. 111). In that case, urban planners need new skills and use new tools in the transition team with a set of *change agents*. Both in UTM and SSP, they need to build governance capabilities used within individual projects (cf. Molenaar et al., 2021). An extensive operationalization of transformative capabilities, notably with regard to governance, engagement, and co-creation, is found in Shahani et al. (2022).

4.2. Development, Participatory Design, and Updating of (Digital) Instruments and City Development Model

As seen in Section 3.4, using transition planning instruments has various challenges and requires planning offices to acquire new capabilities. Notably, digital instruments change planning practices substantially (see e.g., Nummi et al., 2023) and planners need new digital skills to use them (Sabri & Witte, 2023). Moreover, these instruments are typically not developed by the municipal planning office, but rather by a software company and occasionally by an applied research institute. To ensure planners use these instruments ("closing the implementation gap"), they need to be actively involved in their design. Moreover, the actual implementation requires the active contributions of public and private sector stakeholders, decision-makers, and local construction companies in model design to ensure correct representation of urban subsystems and to provide data used in the digital city model. Each transition project in the portfolio (e.g., mobility, energy, waste) requires stakeholder engagement in the formulation of subsystem operationalizations and development scenarios, as well as participatory design of the digital twin or development model, and analysis of experimental or simulation results for decision support. Moreover, external events, renewed insights, as well as the need to analyze previously unforeseen transition projects may call for changes to the digital development model. To remain relevant and useful, the planners need to update the data used and, if necessary, modules in the city development model pertaining to the subsystem transformed. Following such updates, new computational results need to be produced and analyzed. The urban planning office needs to build capabilities for these recurring activities.

4.3. Building Capabilities for Management of and Learning Across the Portfolio of Transition Projects

As emphasized, the long-term urban transition comprises an evolving portfolio of relatively short-term projects transforming urban subsystems. Particularly in the SSP line of reasoning, the urban planning office would hold responsibility for managing this portfolio by initiating projects top-down as well as subsuming interesting ones that are initiated bottom-up (e.g., by local communities, non-governmental organizations, or entrepreneurs). The planning office would need to build legal, financial, and organizational capabilities to initiate, adopt, and develop projects, align these projects with the long-term vision, engage stakeholders in practical implementation, and analyze and deal with interactions between projects.

Given the multitude of projects, the focus of learning for planners is not just *within* individual projects but also *across* both different ones in the same city as well as similar ones elsewhere (See Section 4.4). It becomes relevant to adopt and co-develop methods, instruments, and city development models that can be used in the various projects and possibly analyze the interaction of these projects.

In addition, with the substantial chance of both exogenous changes (e.g., regulations or policies at higher spatial scales, changes in national infrastructures) as well as the emergence of unforeseen endogenous challenges, the long-term planning process is generally not linear but rather iterative, requiring revisions and adaptations. Arguably, developments in projects may force planners to revise the vision or the "radical" transition agenda, which in turn may feed-forward in projects.

4.4. Learning in City Networks at Project Level, Planning Capabilities, and Transition Praxis

Cities are the niches for experimental urban subsystem transformation (cf. Torrens et al., 2019). Some transition projects may be suitable for small-scale experiments that can be rolled out and scaled up. Other projects require costly, near-irreversible, large-scale implementations that do not allow experimentation. In this case, one could use simulation with digital models, for example. Learning about experiments and projects conducted elsewhere may not only spark ideas for new local projects but also provide clues about effective implementations of experiments or projects readily pursued.

In a network of transition cities (e.g., C40, EU 100 cities, Global Covenant of Mayors), urban planners, change agents, and other stakeholders may learn from processes, experiments, and project results in other cities. Clearly, due to local particularities, "best practices" cannot be directly applied to other cities per se (Bulkeley, 2006), but must be tailored to new conditions. Moreover, apart from learning about ideas, particularities, tools, and methods for individual projects, one may also seek insights into planning capabilities, instrumentation, as well as digital city development models for urban multi-system analysis. Note that information shared in such city networks would allow comparative multi-city studies and thus contribute to the development of methods, learning on the role of local particularities, and ultimately the advancement of urban transition theory (Roorda et al., 2014; Webb et al., 2018; Wittmayer et al., 2016).

5. Conclusions and Discussion

Recently, urban transition and planning theory scholars turned their attention to the co-creation of the radical transformation of urban subsystems. However, it is not clear what co-creation is in practice, which instruments exist, and how these instruments can be used effectively. This is partly caused by the ambiguous and rapidly developing conceptions of the urban transition process. Based on SSP and UTM, the urban transition is conceived as a long-term process driven by a co-created vision and agenda with recurring management of an evolving portfolio of relatively short-term co-creation projects to transform urban subsystems (e.g., infrastructures, utilities, services, built environment). This article identifies types of instruments and examines the institutionalization of capabilities for their application and development.

Based on the inventory of instruments, four types are identified (participatory planning and communication, expert planning support systems, urban living labs, and virtual transformation labs) that are particularly suitable either for conceptual exploration or computational analysis, and either for short planning horizons or long-term, iterative co-creation. The co-creation tools and the living labs offer platforms for engagement and vision formulation, whereas the digital tools offer valuable complementary ways to analyze subsystem transformations. Particularly the "virtual transformation lab" is well suited to using city *development* models for strategic decision-making. Given that the three dimensions for classification as well as the clustering of instruments are based on qualitative content analysis rather than theoretical arguments, follow-up research should take a critical look at the typology and instrument classifications.

Given that transition challenges evolve, regular updates to models and data, alignment with planning needs, and continuous stakeholder engagement are essential. In addition, urban transition planners need to engage stakeholders, manage project portfolios, and foster continuous learning within and across projects. This underlines how co-creation with these instruments should be institutionalized within transition planning and management practices. Further case studies are needed to gain insight into the challenges of developing and applying such instruments, as well as building the required capabilities.

The operational and managerial activities thus discerned could be performed by a "Transition Planning Office" (TPO). This TPO could host the capabilities for stakeholder engagement in collaborative planning, participatory design of models, collection of city data, etc. It could manage the portfolio of projects, initiate or subsume projects, provide legal and financial support for individual projects, align projects with the overarching vision or resolve conflicts and exploit synergies between projects. It may deal with uncertainty in strategic planning by making substantive learning within and across projects integral to procedures and the planning mindset.

Moreover, it could build capabilities for all four types of instruments, e.g., contribute to an urban living lab or co-develop a city model for a virtual transformation lab. Additional research is needed to define such a TPO and assess its viability in planning practices. The notion of a TPO extends the conceptual frameworks used. It complements UTM's temporary stand-alone transition arena with active involvement in long-term practical planning and implementation. In addition, it complements SSP's call to make urban planning more strategic by building capabilities for operational planning, managing a portfolio of projects, and developing and using a variety of instruments. Arguably, a limitation of this article is its exclusive focus on SSP and UTM. Further research should explore alternative perspectives on planning (e.g., adaptive urban planning) and urban change (e.g., tactical urbanism), which may offer different conceptions of the transition process, stakeholder participation, or the use of instruments.

Further research is required to examine the place-specificities of transition challenges and the implications for instrumentation and institutionalization. After all, transition challenges and planning practices in megacities differ from those in towns, and those in cities in developing countries differ from those in developed countries (cf. Parnell & Robinson, 2012; Watson, 2016), both in terms of existing and envisioned urban subsystems, infrastructural elements, socio-economic factors, governance capabilities and styles, data acquisition capabilities, and required institutional and instrument developments. In addition, given that urban transition initiatives are embedded in development policies and sustainability initiatives at regional, national, and international levels, greater multilevel alignment may be needed to create a supportive regulatory environment (cf. Bulkeley & Betsill, 2005).

Acknowledgments

The first author and second author gratefully acknowledge funding from the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung [BMBF]) for the project hyBit: Hydrogen for Bremen's Industrial Transformation (Grant 03SF0687A). The first author also acknowledges support from the European Union Horizon Europe programme through Grant Agreement 101132559 (ST4TE: Strategies for Just and Equitable Transitions in Europe). Additionally, the second author gratefully acknowledges funding from the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung [BMBF]) for the project Quarree100: Resilient, Integrated, and System-Serving Energy Supply Systems in Existing Urban Districts With Full Integration of Renewable Energies (Grant 03SBE113B).

Funding

Publication of this article in open access was made possible through the institutional membership agreement between Maastricht University and Cogitatio Press.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning
2025 • Volume 10 • Article 9819
https://doi.org/10.17645/up.9819

ARTICLE

Open Access Journal

Digitalisation in Local Housing Energy Systems: Co-Creation and Digital Literacy in the Dutch Context

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Submitted: 23 December 2024 **Accepted:** 8 April 2025 **Published:** 18 June 2025

Issue: This article is part of the issue "Co-Creation With Emerging Technologies to Address Climate Challenges in Cities" edited by Cesar Casiano Flores (University of Twente), A. Paula Rodriguez Müller (European Commission, Joint Research Centre), and Evrim Tan (University of Munster), fully open access at https://doi.org/10.17645/up.i439

Abstract

This article critically reflects on the digitalisation of local housing energy systems. It looks at two Netherlands-based cases and their implementation, combined with the use of digital tools. From a socio-technical angle, it is crucial to provide energy-consumption dashboards with a two-fold feedback loop for residents about their energy consumption. That enables users to make informed decisions and behavioural adjustments in daily energy usage. By proposing a framework, the article introduces two new analytical categories: digital literacy and co-creation applied to the use of interactive digital tools. The aim is to unpack new challenges of the digitalisation process and the use of dashboards in relation to the two analytical categories. To do so, the article compares two different configurations of local socio-spatial contexts. The analysis draws upon an archive of correspondence, official documents, survey results, participant observations, multiple rounds of group interviews from the funded projects, and new in-depth expert interviews. The results reveal that inhabitants should accept the underlying technology that revolves around decentralised energy systems and be willing to pay their share of the investment costs. Furthermore, the authors discuss the reach of digital literacy and co-creation as emerging urban planning dilemmas. The empirical evidence is that the scale of implementation, the type of engagement with residents (tenants vs. owners vs. communities), the degree of digital literacy, and the opportunities for co-creation activities are essential features for a more inclusive digitalisation outcome.

Keywords

co-creation; digital literacy; digitalisation; housing energy system; The Netherlands

1. Introduction

The deployment of technologies such as sensors and energy consumption (Lock et al., 2020) at the citizen level has garnered considerable attention for their potential to unveil and track environmental impacts (Coenen & Hoppe, 2022). These technologies are intended for optimal systems, such as heating systems, electricity grids, or integrated systems encompassing electric vehicles, mostly from a technical engineering perspective (Hoppe et al., 2016). This perspective predominantly focuses on technical considerations, including energy utilisation and production, CO_2 emissions, and, at times, a technical-economic analysis aimed at cost optimisation. Despite the wealth of information garnered, the efficacy of these tools in driving substantive changes in environmental policy and individual behaviour is brought into question (Kitchin & Dodge, 2014). This scepticism is further compounded by the observation that, over time, consumers may disengage from these dashboards: Familiarity breeds a sense of complacency (Kramer & Petzoldt, 2022; Timm & Deal, 2016). The normative views about the implementation of technologies that present seemingly objective assessments due to their technical capabilities (Mattern, 2021) are debatable because they underscore the paradoxical reality that these seemingly eco-conscious digital tools often rely on energy-intensive infrastructures like data centres. This raises questions about their net environmental benefit. While these technologies excel in quantifying data related to pollution levels, tree coverage, and air quality, the translation of such data into meaningful policy alterations or tangible action remains a subject of contention, as articulated by Broussard (2018). Although technologies like sensors and dashboards for energy consumption at a citizen level have proven effective in recognising and tracking environmental impacts, there is evidence highlighting their environmental cost, given their reliance on energy-intensive infrastructures (Edwards, 2013).

With the recent advancements in data visualisation and AI technologies, some critical scholars argue that there are alternative ways of understanding the digitalisation process and its spatial articulation which are overshadowed by the dominance of smart city discourses and computational and algorithmic perspectives (Alvarez Leon, 2024; Dekeyser & Lynch, 2024). By embracing this critical approach, the article explores the following research questions:

> RQ1: How is the digitalisation process affecting the configuration of local housing energy systems?
>
> RQ2: What kind of digital tools are implemented, and how in relation to socio-technical features (actors and technologies) in two cases?
>
> RQ3: To what extent do digital literacy and co-creation activities play a role in optimising the use of the systems, and how are they enabled?

The comparison between two cases in the Dutch context is to maintain rigour in the same kind of regulation in energy transition projects in local housing systems at a national level. The purpose is twofold: theoretically and analytically, to introduce two emergent categories and potential dilemmas in urban planning and in a broader research context; empirically, to draw evidence from these two projects and the new research which contributes to how community members, researchers, and digital experts together can realise a more inclusive digitalisation process preventing spatial unevenness. The common ground of the analysis is the use of dashboards and similar technologies to enable citizens to play their role as agent of change in local energy systems (energy demand control in relation to their technical skills) and adapt their behaviours accordingly (their degree of digital literacy). Digitalisation is a process in which co-creation is the component that facilitates the acquisition of an adequate degree of digital literacy to ensure optimal use of the local housing energy systems within communities.

The notion of digital literacy is operationalised as a mutually inclusive element together with the technical set of skills to use the system. In other words, understanding the energy system and using the dashboards by final residents determines the behaviour adjustment and, therefore, the reduction of CO_2 consumption. This article draws on cases from two separate research projects in which the authors were involved. The first case, the Oude Weverij – Het Indië-terrein, in Almelo, was the demo housing project within the broad research project funded by the Netherlands Enterprise Agency (RVO). The second case, Aardehuis, in Olst, was the Dutch pilot housing project in the European Horizon 2020 project SERENE – Sustainable and Integrated Energy Systems in Local Communities. In the first demo housing project, the research group developed and tested management for decentralised energy systems, including battery storage (RVO, 2024). In the second pilot, the research group observed participation in local energy communities in relation to sustainability goals and the socio-economic aspects of the roll-out of new energy technology niches in the demos (SERENE, 2024).

Based on the abovementioned prior research project results obtained through the RVO and Horizon funds, the operationalisation of the concept of digital literacy adds novelty and relevance to the deliverables published from the two projects. The selection of the two use cases is based on both commonalities and dissimilarities to emphasise how these instances in the same geographical area (province Overijssel, Twente region) can have a very different impact in terms of effectiveness in the use of specific technologies. Regarding the scale of projects, both are local small-scale implementations, and, in terms of geographical scale, the Oude Weverij – Het Indië-terrein in Almelo can be defined as urban, and the Aardehuis, in Olst, as rural. The main difference between the two Dutch use cases is that Almelo involves tenants renting apartments who not keen to adapt their behaviours, while Aardehuis is a cohesive community driven by eco-centric values. In the latter, they emphasise sustainability with self-managed energy systems, benefiting from higher community involvement and mutual trust. Besides the diverse community vision and sense of belonging more present in Olst, the scale and the aspect of co-creation remain central factors. The critical insight is that mere monitoring does not inherently influence energy consumption behaviours, particularly when the user's interest declines or financial incentives fail to provide tangible benefits that are readily perceived. To optimise the use of these systems, inhabitants need to contribute through their specific behaviour, either in their energy use or willingness to invest in a savvy use of energy technology at a local scale. Findings indicate that there are challenges in terms of planning and spatial unevenness. For instance, access to advanced energy systems is limited and often perceived as a privilege. The main common findings highlight that digital literacy, co-creation, behavioural motivation, and community sense of belonging are key to the adoption and optimal use of sustainable technologies. What plays a role here is the different scales of spatial developments which face regulatory hurdles, especially with older grid infrastructure.

The article is structured as follows: the next section is about digitalisation in local housing energy systems, focusing on dashboards, digital literacy, and co-creation; the third is a brief methodological note; the fourth is the presentation of the two use cases. The fifth and the sixth are sections dedicated to the discussion of results and conclusions.

2. Digitalisation in Local Housing Energy Systems

Smart technologies do not only pertain to technological elements or economic benefits—they also interact with a human factor and behavioural dynamics by final users (Coenen & Hoppe, 2021). According to Parra et al. (2017, p. 739), local housing energy systems in combination with smart technologies might "increase the amount of renewable energy generation consumed locally, they provide opportunities for demand-side management and help to decarbonise the electricity, heating and transport sectors." The digitalisation process of housing energy systems entails mainly the use of smart technologies, such as interactive dashboards designed for consumers. Scholars in environmental psychology review and evaluate the effectiveness of interventions designed to encourage households to reduce energy consumption, categorising them into antecedent and consequent strategies. These studies provide valuable insights into how social norms can influence energy conservation behaviours by offering insights from behavioural economics and psychology to explore the cognitive biases and motivational factors that may explain why energy-related behaviour often fails to align with consumers' personal values or material interests. The factors of urgency, knowledge, motivation, and investment capability are often linked to social norms as influencing reasons (Abrahamse et al., 2005; Frederiks et al., 2015). In this article, the relationship between digitalisation and the use of dashboards and these behavioural components are taken into account. The objective is to analyse the factors that compose the social part of the system along with the digital tools, which are the technical components. The combination of both is to obtain the desirable use of these socio-technical systems; thus, a certain degree of digital literacy is expected from the final users. Co-creation activities might certainly enhance and increase awareness and, therefore, improve the degree of digital literacy and corroborate existing technical skills. The article argues that the combination of these elements is the condition sine qua non to assure effectiveness at a societal level and to reduce the carbon footprint in energy consumption.

2.1. Digital Literacy and Co-Creation: Towards a Framework

In an increasingly digitised world, the concept of literacy extends beyond traditional reading and writing skills to encompass digital literacy, which is crucial for navigating the complexities of the digitalisation process (Van Dijk, 2012). Digital transformations in the urban environment put digital literacy and technical skills in a central and significant role in shaping socio-economic dynamics and behavioural patterns of individuals in our society (Townsend, 2013). Studies in pedagogical design are pioneering in introducing the concept of digital literacy in relation to learning and educational activities, which affect directly behavioural factors. Digital literacy, as highlighted in scholarly discourse, stands as a pivotal challenge in the seamless integration of technology within academic realms (Blau et al., 2020). Its essence is encapsulated by defining it as the repertoire of competencies and skills indispensable for navigating the labyrinthine and multifaceted information landscape fostered by digital media. Eshet-Alkalai (2012) defines digital literacy as a multifaceted concept in which three distinctive categories can be identified. First, there is the realm of photo-visual thinking, which pertains to the adept understanding and proficient utilisation of visual and data represented in graphs and captions. This is about decoding and encoding messages conveyed through images and multimedia presentations, an essential skill in today's visually-driven digital environment. Second, real-time thinking comes into play, necessitating the ability to process a myriad of stimuli simultaneously; this skill is particularly crucial in dynamic digital contexts where information bombardment is commonplace. Last, information thinking involves the critical evaluation and synthesis of data sourced from diverse digital outlets; in an age of information overload, the capacity to discern credible sources and amalgamate disparate pieces of information is indispensable. Moreover, Heitin (2016) defines digital literacy as "the ability to use information and communication technologies to find, evaluate, create, and communicate information, requiring both cognitive and technical skills," emphasising the trifecta of finding and consuming digital content, creating digital content, and communicating or sharing digital content.

Within contemporary debates in urban studies, the concept of digital literacy is not under the radar yet. The first attempts mainly focussed on disparities in digital skills and how these affect technology use, discussing the digital divide in urban and social contexts (Hargittai, 2001; Selwyn, 2004). More recent works suggest that the definition of digital literacy and its relation to contiguous concepts such as digital citizenship remains nebulous and often divergent (e.g., Helsper & Eynon, 2013; Nichols & Stornaiuolo, 2019). Thus, with the emergence of the concept of digital literacy and different skill pathways that lead to digital engagement, there is an urge to grasp the complexities and divergences in digital literacy among individuals and in synergy with the notion of digital citizenship. For instance, digital literacy serves as a gateway to accessing housing opportunities and welfare benefits in today's digital age. Individuals proficient in utilising online platforms can explore a wider range of housing options, conduct thorough research, and engage in virtual tours or online applications. This access empowers individuals to make informed decisions about housing, potentially enhancing their socio-economic standing. Conversely, those lacking digital literacy may face barriers in accessing housing information and services, exacerbating existing inequalities. In essence, the discourse surrounding digital literacy underscores its multifaceted nature, intertwining various technical and non-technical elements. By framing digital literacy in these analytical dimensions, this section provides valuable insights into the effectiveness of digital tools and real-time feedback in promoting energy conservation behaviours.

The article introduces digital literacy adapted to decentralised housing energy systems and consumption. This functions as an operationalised concept in terms of the ability to access, manage, understand, integrate, communicate, evaluate, and create information safely and appropriately through digital technologies for energy consumption. The adopted theoretical background includes competencies that are variously referred to as computer, ICT, information, media, and energy literacies, by acknowledging all these distinctions in one definition applied in the two use cases (see the discussion in Section 5). In particular, dashboards are an object and a digital tool in which a certain degree of digital literacy is required to optimise their use. Tools are the connection points between using information, demanding response reaction, and seeing the effect of the demand response behaviour. To do so, there is a need to include physical, social, economic, and environmental principles concerning urban planning, such as community engagement activities and co-creation. These activities guide the development, design, and leverage of technology to improve urban management, infrastructure, and services (e.g., smart grids, decentralised energy usage), as well as use data-driven approaches to enhance efficiency and responsiveness. In the proposed digital literacy framework (see Figure 1), co-creation activities and collaboration among stakeholders are taken into account to generate functional and inclusive environments.

Co-creation is a term used by many fields to refer to either a "theory of value" focusing on how entities co-create value with users through collaboration, a set of practices that function as design methods, or both (Jukić et al., 2022). Co-creation involves a cooperative effort between public and private stakeholders to address a common public issue or objective. This process includes sharing different resources to collaboratively initiate, design, and/or implement ideas, strategies, policies, regulatory structures, or technological innovations (Hofstad et al., 2022). Recent work on co-creation demonstrates how co-creating urban data dashboards with community partners can lead to insights and actions grounded in residents' experiences, aiming to achieve social change: "Co-creation of urban data and informatics with community partners facilitates the development of insights and actions that are grounded in residents' experiences and aimed at achieving social change" (Nidam et al., 2024).

Conversely, the study by Jones (2019) examines the role of participatory urban dashboards in urban planning and decision-making processes. Jones (2019, p. 59) claims that "it is to co-create dashboards with communities that are portrayed by, and potentially affected by decision-making that occurs in response to, urban dashboards." On one hand, under these conditions, practices of co-creation have become notably prominent as successful governance arrangements (Rodriguez Müller et al., 2021) for leveraging local knowledge and perspectives to forge innovative approaches (Torfing et al., 2019). On the other hand, using Steen et al.'s words (2018, p. 293), there is a critical side of it which pertains "the darker aspects of co-creation and co-production, particularly in the context of public services and citizen engagement." However, this evolving approach presents challenges and paradoxes, particularly because it involves the participation of diverse stakeholders, each with their own unique backgrounds and perspectives. Such diversity can lead to increased conflict, necessitating advanced conflict resolution strategies, and may even result in the co-destruction of established norms and structures. Insights into the dynamics of co-creation and co-production in public services emphasise the need for effective conflict resolution strategies and the potential for innovative approaches through citizen engagement (Tappert et al., 2024).

Building on the abovementioned work and starting with the assumption of the embeddedness of digital platforms with an urban character and participatory features for citizens (Chiappini, 2020; Chiappini & de Vries, 2022), this article situates digital literacy in the context of energy consumption and residents' behaviour adaptation. As a theoretical tool, the framework analyses energy-oriented projects rooted in urban studies epistemology. In applied terms, it shows how to optimise energy usage through a combination of technology, collaboration, and behaviour adjustment. As Figure 1 illustrates, the central component is related to the concept of digital literacy, conceived as the ability of residents and stakeholders to effectively use and understand data visualisations provided by digital tools, such as dashboards and technical affordances. Practical examples of technical affordances are choices made by software developers and engineers, for instance, the function of scrolling, visual graphs, and swiping right or left.

These dashboards present insights into daily energy consumption and provide functions (i.e., technical affordances—see Figure 7) to help adjust behaviours in a specific socio-spatial context in which the scale of implementation plays an important role in the success or failure of the project.

To break down the key components and their vectorial relations in Figure 1, the digital tools (top box) as dashboards are emphasised as tools that provide functions that enhance usability, functionality, and decision-making. These tools rely on design and technical features that make data intuitive and actionable. The tools act as a medium to improve digital literacy by making energy consumption patterns visible and understandable. The stakeholders (left corner) include municipalities and other organisations responsible for housing energy systems. Their role is to design, implement, and provide technological and infrastructural support for digital tools. The residents or citizens (right corner) represent the primary users of the

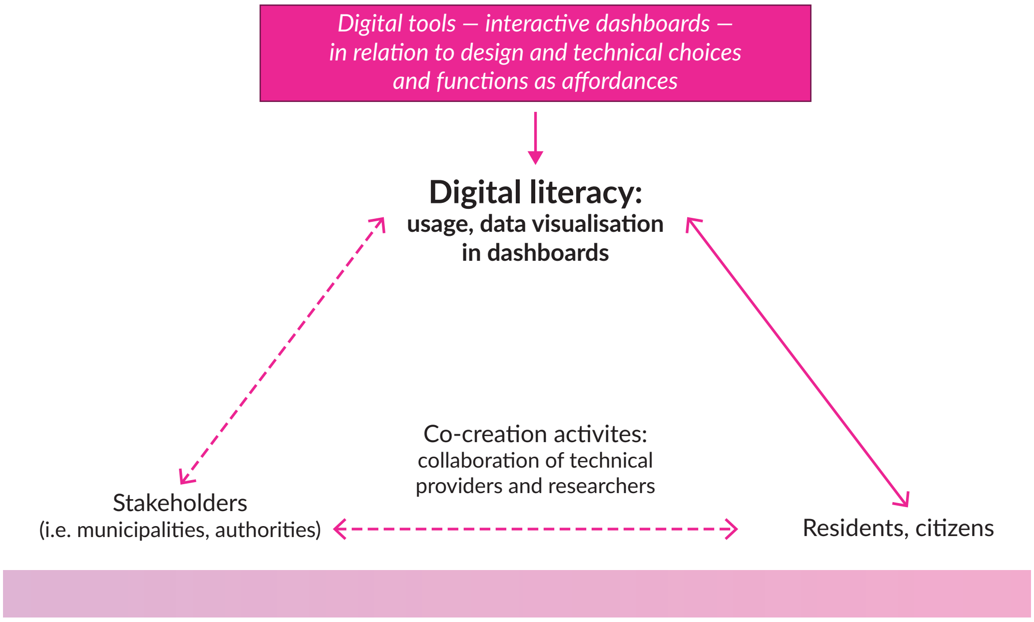

Figure 1. Digital literacy towards a framework.

dashboards. Hence, their role is to engage with these tools to understand their energy usage and make adjustments to align with optimal energy consumption behaviours. The co-creation activities (bottom box) refer to the potential collaboration between technical providers (i.e., developers of dashboards and energy systems) and researchers. This is vital to ensure that the tools are user-friendly, effective, and responsive to the needs of both stakeholders and residents. While co-creation involves collaborative approaches among stakeholders for developing solutions, digital literacy is essential at an individual level for the effective understanding of the use of these tools. In the discussion section, the framework functions as a heuristic tool in the analysis of the two use cases and situated in a broader debate in urban studies.

3. Methodological Note

The methods employed are rooted in a qualitative approach and integrate multiple rounds of primary and secondary data collection. To explain the steps of the research, there are two main phases in which data were gathered through different rounds and techniques. The first phase of primary data collection happened within the two funded projects in which the authors were involved as university partners: Oude Weverij (funded by RVO) and Aardehuis (funded by Horizon 2020-SERENE). From 2018 to 2022, residents have been participating in surveys and face-to-face rounds of individual and group interviews. Participant observations have been conducted during offline and online official meetings between stakeholders. The first phase enquired about socio-technical elements, namely, how the different elements in the local housing energy system (PV, heat pumps, storage, users) can be optimised and how the residents are keen to adapt their behaviours according to them (RQ1 and RQ2). In 2024, the second phase of data collection started, in which the prior material was revised in light of the new analytical categories of digital literacy and co-creation (RQ3). Specifically, the prior collection of primary source data allowed for first-hand access to an extensive archive of empirical data and documents to re-contextualise the two use cases. To collect new empirical material, in which digital literacy and co-creation are the new elements to include in the framework, four in-depth expert interviews were conducted. Finally, the article uses digital ethnography notes and multimedia material (e.g., screenshots), capturing real-time interactions and socio-spatial dynamics in the two cases. Table 1 illustrates the operationalisation of the area of inquiry linked to the deployed methods and the multiple rounds of data collection and how the research questions tackle the different aspects of the analysis.

Table 1. Overview of the type of methods and rounds of data collection linked to the research questions.

	Methods and rounds of data collection		RQ
	Oude Weverij	Aardehuis	
Local housing energy system and configuration	Prior survey. Two rounds of official document analysis, meetings with partners and stakeholders (mostly in Dutch 2020–2022).	Prior survey. Two rounds of official document analysis, meetings with partners and stakeholders (mostly in Dutch 2020–2022).	1
Type and use of digital tools (digitalisation features: decentralised energy system, dashboard)	Two rounds of group meetings/interviews with tenants of the six units (from 2018—interrupted in 2020 by the Covid-19 pandemic). Participant observation of meetings and digital ethnography (2022–2024).	Two rounds of individual interviews with 12 residents (2018–2022). Participant observation, digital ethnography of meetings (2022–2024).	2
Enabling digital literacy and co-creation activities (during and after implementation)	Secondary data analysis based on prior data collected during the Oude Weverij (RVO project) and Aardehuis (Horizon 2020-SERENE) in 2024. One round of four expert in-depth interviews in 2024 (conducted in English)*.		3

Note: * The four experts (two researchers and software developers at Saxion University of Applied Sciences; one business advisor, director of the Sustainable Innovations Academy in the Netherlands; and one policymaker and consultant in the Innovation Section of the Municipality of Amsterdam) were selected with criteria based on their function in the representative organisation; the in-depth interviews were structured to gather new empirical material on the analytical categories of digital literacy and co-creation; the experts are, to a different extent, directly involved and have knowledge of both of the use cases.

4. Two Use Cases in the Dutch Context

Prior management studies which focused on energy systems indicate that digital tools which aim at behaviour change interventions can lead to an average reduction in energy consumption of 4 to 12 percent, with maximum savings surpassing 20 percent (Nachreiner et al., 2015; Tiefenbeck et al., 2018). As mentioned in the introduction, this article draws on two separate funded research projects—in which different phases of research were conducted from 2020 to 2024. While digital literacy was not the primary focus of either project, it emerged during the research as a key factor influencing the effectiveness of the interventions in both cases. In both cases, the residents of the housing energy system had the opportunity to reduce their carbon footprint and contribute to making homes and their energy systems more sustainable and more based on renewable energy through the use of an interactive dashboard. The Aardehuis case, as part of a European project, aims to demonstrate cost-efficient and consumer-oriented approaches to merging various energy system providers (Bak-Jensen et al., 2024). This merging is crucial for the sustainable growth of regional communities by enabling them to fulfil their energy requirements using local renewable sources and push for a shift towards a more sustainable housing system (Koirala et al., 2016). This shift also promotes a more decentralised configuration of the electricity system and the deployment of digital tools, aiming at a combination of principles between sustainability and digitalisation. Hence, we ask: How is the digitalisation process affecting the configuration of local housing systems? The objective of the Oude Weverij – Het Indië-terrein housing demo project in Almelo is the experimental development and application of a user-centred housing energy system, including battery and heat storage through smart energy management and behavioural incentives (Riezebos, 2024). In the Oolst case, residents are familiar with the energy system and understand the need for (information from the) dashboards. In the Almelo housing project, the problem begins with understanding the overall energy housing system. Participation and user co-creation can be on the level of the system and the level of the dashboards. As a result, this was the initial problem which was exacerbated because the citizens eventually were not involved in creating the system (which included the dashboard and related demand control measures). Hence, it has been selected by the authors to study the implementation and functioning of the dashboard as well as its social and spatial implications and the benefits of wider application. In both cases, the dashboards offer real-time feedback loops and data visualisations through graphs to promote energy conservation behaviours.

4.1. The Use Case of the Oude Weverij: A Decentralised Energy Housing System With Its Constraints

The use case of the Oude Weverij – Het Indië-terrein is located in Almelo, Overijssel (see Figures 2 and 3). The project presents a decentralised housing energy system (see Figure 4) and the connected dashboard, which seeks to demonstrate the environmental sustainability and feasibility of these systems. The total of the eight houses are rented with a heat pump and solar panels to power up the system in which the heat is delivered for a market-conforming tariff. Moreover, there is a collective battery to store the surplus of solar electricity on sunny days and used for the heat pumps. Thanks to this system, in principle, the residents reduce their carbon footprint, which implies a behavioural change in energy use rewarded through financial incentives. In 2022, the RVO research team started to examine the sustainable energy system's technical functioning and social and economic implications. The economic implications are strickly related to the capacity of residents to adapt their behaviours and benefit of the financial incentives within the Dutch national regulatory setting.

Figure 2. The Oude Weverij – Het Indië-terrein houses, Almelo: Rendering of the project. Source: Riezebos (2024).

The main stakeholders and partnerships in this project are Ter Steege Bouw Vastgoed Hardenberg and Ter Steege Advies & Innovatie, as well as the battery supplier (Contour), installation consultant (Loohuis Energie & Installatie-advies), grid operator (Coteq), and the University of Twente (RVO, 2024). The residents of the eight houses are all new tenants who find themselves primarily as energy consumers, with limited involvement in the implementation of the dashboards. The heat consumption is connected to the use of the dashboard. Although residents have been blandly pushing to collaborate and share information with neighbours and surveys about

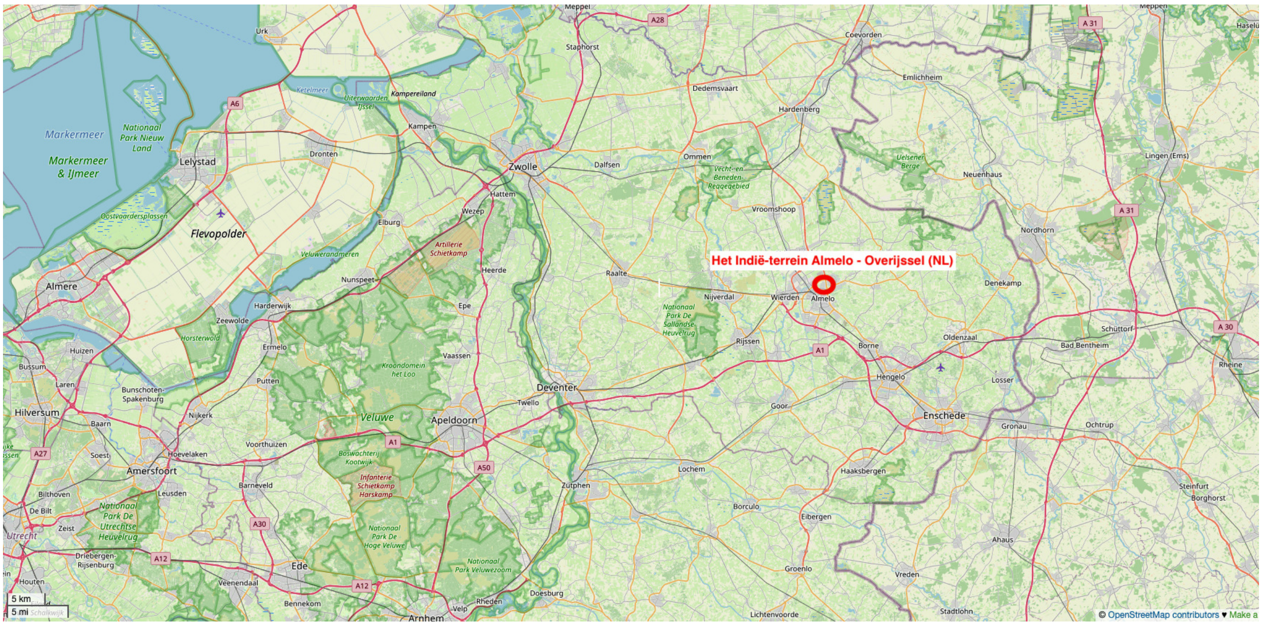

Figure 3. Map and location of the Oude Weverij – Het Indië-terrein, Almelo.

their daily energy consumption the desirable win-win situation did not work out as expected. While they benefit from access to renewable energy via the technical system, residents are encouraged to learn from each other and exchange know-how and tips and tricks about the use of the dashboard. However, they face challenges in how they interact with the system and adapt their behaviour accordingly. The project's advanced energy grid offers new possibilities, but it also introduces obstacles in understanding and adapting to the housing energy system. For this type of energy use that has to flow to the inhabitants and to the project owner to correct the bills, it is crucial to ensure the proper reading of the data on the dashboard according to the use of the system. When these decentralised issues are not disentangled by tenants, it leads to split-incentive problems, which are extra challenges to tackle.

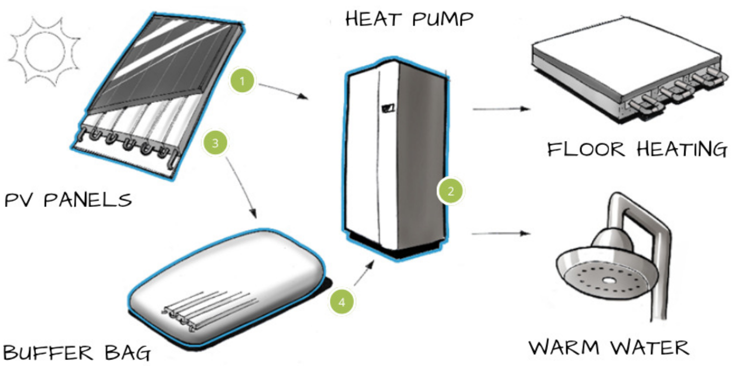

Figure 4. The decentralised energy housing system in Almelo. Source: Riezebos (2024).

4.1.1. The Split-Incentive Problems and the Lack of Collaboration Among Tenants

The split-incentive problem and lack of collaboration among tenants in local housing communities present significant challenges to implementing sustainable housing practices and improving the use of dashboards.

The split-incentive issue arises when the costs and benefits of energy-efficient investments are divided between landlords and tenants, reducing the motivation for either party to act. For instance, the Almelo case shows how tenants are reluctant to adapt their energy behaviours without recognising the reap translated into financial benefits. During the testing phase, “co-creation” could have been implemented as part of both “collaboration” and “shared activity” such as workshops or tutorials with the tenants and the owners. As a result, tenants have little incentive to initiate or fund such improvements, as they do not own the property and may face uncertainties about the duration of their tenancy. Although the degree of digital literacy is not directly measured, as a proxy, the use of the dashboard indicates that it was not effective. This misalignment of incentives is compounded by the lack of collaboration among tenants, often due to diverse interests, socioeconomic backgrounds, or transient residency. Without a collective voice or cohesive effort, tenants struggle to advocate for shared improvements, further perpetuating inefficiencies and suboptimal housing conditions. Addressing these challenges requires innovative policies, such as split-incentive programs, tenant education initiatives, and community engagement strategies to foster collaboration and align interests between landlords and tenants, all of which which have been lacking in this specific use case.

4.2. The Use Case of the Aardehuis Project: An Eco-Centric Community and Its Dashboard

Michael Reynolds’ Earthship architectural concepts served as the inspiration for the innovative ecological housing project known as Aardehuis/Aardehuizen (or in English Earthship community). Located in Olst, Overijssel (see Figures 5 and 6), the housing project and its specific architectural style integrates power, water, and heating into the design process and places a high priority on using sustainable and recycled materials during construction (Aardehuis, 2024). The building of the houses, for a total of twentythree units, started in 2011 and concluded in 2015. The plan for the project consists of an investment of €5,500,000 for the realisation of the housing (Aardehuis, 2024), with solar panels to supply 32 percent of the whole electricity demands (de Graaf, 2018). The local housing system is controlled by an interactive dashboard, which has been designed and implemented with the support of a team of researchers and technical experts

Figure 5. The Aardehuis eco-centric community, Olst. Source: Aardehuis (2024).

(Schillinger et al., 2022). The project gathered considerable traction with the help of community volunteers and environmental enthusiasts. It is an example of what digitalisation and eco-friendly living might entail, incorporating garbage recycling, renewable energy, and rainwater collection through the use of digital tools. The realisation is a result of cooperation between three main constellation of actors: the first, the Aardehuis' Collective Private Commissioning project which was accepted by the municipality of Olst-Wijhe, the second, SallandWonen social housing cooperation together with the construction of three rental homes within the community; and the third as BAM Woningbouw which assisted in sourcing building materials and safety instructions (Aardehuis, 2024).

The recent collaboration between the Aardehuis project and the SERENE project has expanded the production of knowledge around this project, which was included as part of the Dutch pilot coordinated by the University of Twente and the research group Ambient Intelligence at Saxion University of Applied Sciences (AMI). This second use case of local housing energy system includes photovoltaic installations, hybrid heat pumps, battery storage and management systems, smart grid control, energy trading with neighbours, and electric vehicle charge-sharing systems (SERENE, 2024). To track their energy usage, the AMI research group gave the owners within the community an interactive dashboard that would further motivate and support long-term energy-conscious behaviours. The group of researches expected behaviour modification techniques via the use of digital tools to accomplish the mission of reducing energy consumption through smart technologies—such as the dashboard. The researchers designed the layout, technical affordance, and navigation of the dashboard as well as the user interface design, relying on sensors on a local scale with a discrete number of users. All these components are defined as a smart systems. These sensors, for instance, detect movement within the house, or they could be used as ambient sensors that are installed in the homes of the residents to measure electricity usage and share data among inhabitants. The collaboration with users and co-creation activities with the researchers produced a single dashboard design that shows the outputs and insights of the recently smartened electrical grid and offers useful feedback to encourage consumers to spend less energy.

Figure 6. Map and location of Aardehuis project, Olst.

4.2.1. The Interactive Dashboard

The researchers were in charge of creating an interactive energy analysis tool that is user-friendly and accessible, as well as embedding all necessary functions and technical affordances to visualise information for communities (e.g., graphs for the weekly level consumption). The deliverable for this project was a prototype with a dashboard in connection to energy consumption (Aukes et al., 2022). The primary goal of this project was to construct a dashboard that could be used for further development. Throughout the implementation of the dashboard, desk research, literature review, testing, prototyping various iterations, and surveys were conducted by the universities involved (see Figure 7).

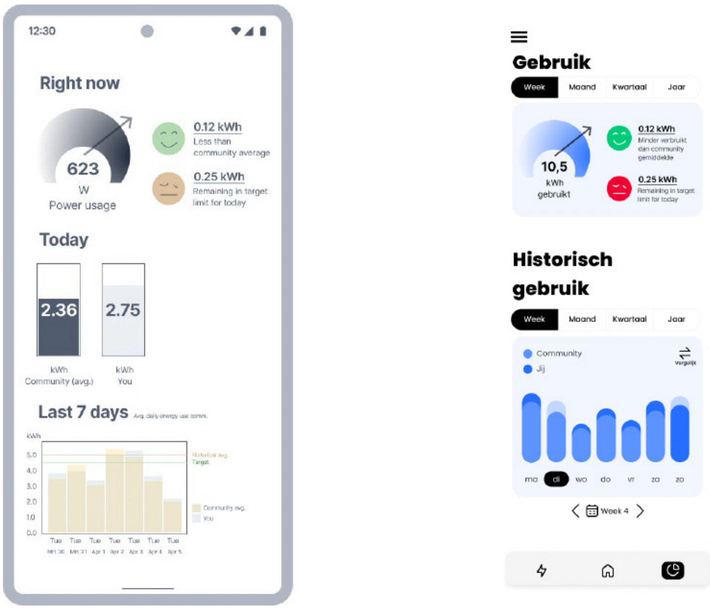

Figure 7. These are the different windows and visualition of the interactive dashboard used on a smartphone. The first on the left indicate the daily and weekly energy, the second image on the right is the version in Dutch. Both images are taken from the second round of iteration and testing. Source: Bornebroek (2023).

The dashboard was designed with the expectation that it would provide a solid basis for the whole research. Thus, the project's overall outcome offers a robust set of feedback and insights for future implementations. The Olst community is engaged with frequent co-creation activities and direct contacts with the designers and software experts. The following section discusses similarities and differences between the two cases with respect to the categories of co-creation and digital literacy. The crucial reflection is on how these emerging categories can exacerbate dilemmas in urban planning and spatial unevenness.

5. Discussion: Digital Literacy and Co-Creation as (New?) Dilemmas in Urban Planning

Before proceeding with the discussion of the results, it is important to acknowledge the limitations of comparing these two use cases based on the different sets of actors, scale and spatial patterns, as well as the chronological dimension of the development of the two projects. One of the main differences is the type of communities for the two use cases: The former is a group of tenants who rent the apartments from landlords, and the latter is a more cohesive community that decided to live according to eco-centric values. The second use case is particularly compelling as a community-driven sustainability initiative due to its self-managed energy service. Yet living in these houses and with these systems can be considered a privilege, as not every neighbourhood or portion of a residential area has access to these benefits. One can significantly lower their carbon footprint, but there is a requirement which is a high degree of digital literacy that goes beyond the basic technical skills (e.g. using a commercial app for purchasing products), motivation in behaviours, and sense of belonging to a certain community, either for ecological or solidarity values in a rural setting. As Viano (2024) claims, local and urban communities increasingly rely on digital technologies. There are many examples of the urban and cultural-symbolic economy and its effect in terms of gentrification and spatial inequalities, in a fashion of the "hipster economy" (Gerosa, 2024) or in the "cappuccino city" (Hyra, 2017). Therefore, the two maps (cf. Figures 3 and 6) are not merely about the location of the use cases but show where this potential spatial unevenness might start, which has to do with the lack of participation by tenants in the first use case and, on the contrary, with a semi-rural community that benefits and has the privilege to live sustainably in the second case. The acceptance of a certain technology is strictly related to a path-dependency, and the attainment of permits for new construction endeavours, especially in cities or nations characterised by a less robust grid infrastructure such as inner-city developments, proves to be an obstacle.

One of the main challenges that co-creation activities with digital technologies for climate change adaptation can face is the level of engagement with users. Co-creation activities are needed, but the effectiveness might differ based on the type of community. In Almelo, tenants were not engaged from the beginning due to a lack of resources to organise these moments of participation. If one does not feel part of a community, there is no intrinsic motivation to attend any activities related to it. In terms of acceptance and dilemmas in planning at any scale, the split-incentive problem (see Section 4.2.1) is an example of how co-creation practices might address these obstacles. For instance, in the first use case, the tenants were not properly informed and guided due to Covid-19, which significantly impacted the project for two years. In other words, no co-creation activities or participatory meetings were organised. The interviews with tenants reveal that only a PDF manual was given with technical instructions and pictures. Conversely, in the Aardehuis community, there were several moments in which the residents felt part of the implementation of the technologies and there was no split-incentive problem as the owners paid themselves, although sometimes collectively, for only a few shared bills. As in the last workshop conducted, the inhabitants do not want more advanced technology or new apps—they want to reduce their digital footprint and keep the essential digital tools. Formally, a collective private commissioning agreement has established a robust foundation that fosters mutual trust within the community and encourages the integration of new members. This could open up a dialogue with the community to manage expectations and build their willingness to adapt to certain levels of inconvenience and flexibility in using the digital tool. Due to several reasons and the contingency of the pandemic in 2019–2020, in the Oude Weverij, tenants were not involved in the decision-making process. In the first round of interviews, one tenant declares:

> I always open the window during the day, I do not really check the dashboard. There were no moments in which they explained how to use it. Besides these group meetings, we don't have any assistance. (group interview with tenants—translated by the authors from Dutch to English)

A few of them confirmed that they did not see the collective purpose of using the system properly. If an expert had educated them on the benefits of these behavioural adjustments, the project could have improved in terms of overall system efficiency:

> The sustainable energy system and the fact that the houses are well-insulated ensure that heat is retained for a long time and that there are hardly any temperature fluctuations. They often do not understand or consider the effort to keep the temperature stable and do not open any windows during the day. Rather in the morning or evening when it is necessary. As tenants, they did not receive enough support during the implementation. A PDF manual was delivered to them. (business advisor—in-depth expert interview in 2024)

In the second use case, it is evident how the co-creation activities have prevented the failure of the project and have strengthened community building amongst owners. The researchers confirmed that the iteration phases are crucial to adapting the technology and helping the users. Some feedback after the co-creation activities was the following:

> We received comments, such as it is not smart to implement that function right now. Some people ask for graphs and size over numbers and catchy visuals. Also, to see the symbol of euros, more green imagery, and funny “stickers.” They say that helps. (researcher—conducted in English—in-depth expert interview in 2024; “stickers” translation by the authors)

It’s not merely about mastering digital tools but also about cultivating critical thinking, creativity, and social adeptness in navigating the complex digitalisation process and in relation to energy consumption reduction. In this article, the notion of digital literacy also encompasses the daily use of smartphones, such as emojis and stickers. As the above quote from the interview displays, the requests are quite mundane and concern the visual and aesthetics of design choices and technical affordances used in the dashboards. Furthermore, the requests can indicate a tech-savvy approach from the communities. For instance, the co-creation activities and workshops organised by researchers indicate that in Olst there is a desire for fewer digital tools, which does not mean less digital literacy but more awareness:

> Let’s say just like a little tablet on the wall yeah where like a smart hub where you could see the information, but you don’t need to have your phone. During the regular meetings with the community, they said that they want less and less complicated affordances in the digital tools they use.…These iterations are very important to adjust the dashboard and to avoid new apps on their phones. (researcher—conducted in English—in-depth expert interview in 2024)

As one of the Saxion University researchers involved in the implementation of the dashboards claims:

> [In Olst]…we are working specifically with the community here in the Netherlands, which is a very small community, where all of them have like this vision of how you should live about energy-conscious behaviour, no footprint and all these kinds of things. It is not an average community. (policymaker—conducted in English—in-depth expert interview in 2024)

This prompts consideration of whether these projects could delve into the public’s discussion on how to educate the Alemelo use case to embrace the use of technology, whether at a community or individual level, fostering greater adaptability within the system. It is important to specify that it is difficult to find training programs or policy interventions to improve the degree of digital literacy at an urban or national scale. Smaller and more cohesive communities in which there is trust among dwellers are the ideal conditions that could enhance participation and a collective understanding of digital tools. For instance, collective and mutual support from neighbours is the most caring manner to improve the degree of digital literacy. Not top-down with digital education programs but solidarity and small-community activities. Thus, the opportunities for scaling up these projects are co-dependent on the type of communities, the capabilities to organise co-creation activities at a collective level, and digital literacy enhancements at an individual level. Digital literacy requirements and co-creation activities are crucial to maintaining these projects beneficial at a societal level. The discussion of findings helps to refine the digital literacy framework. The key takeaway is visually represented in Figure 8, which indicates how fostering digital literacy through tools like interactive dashboards can create a feedback loop between residents and diverse stakeholders to optimise the final use.

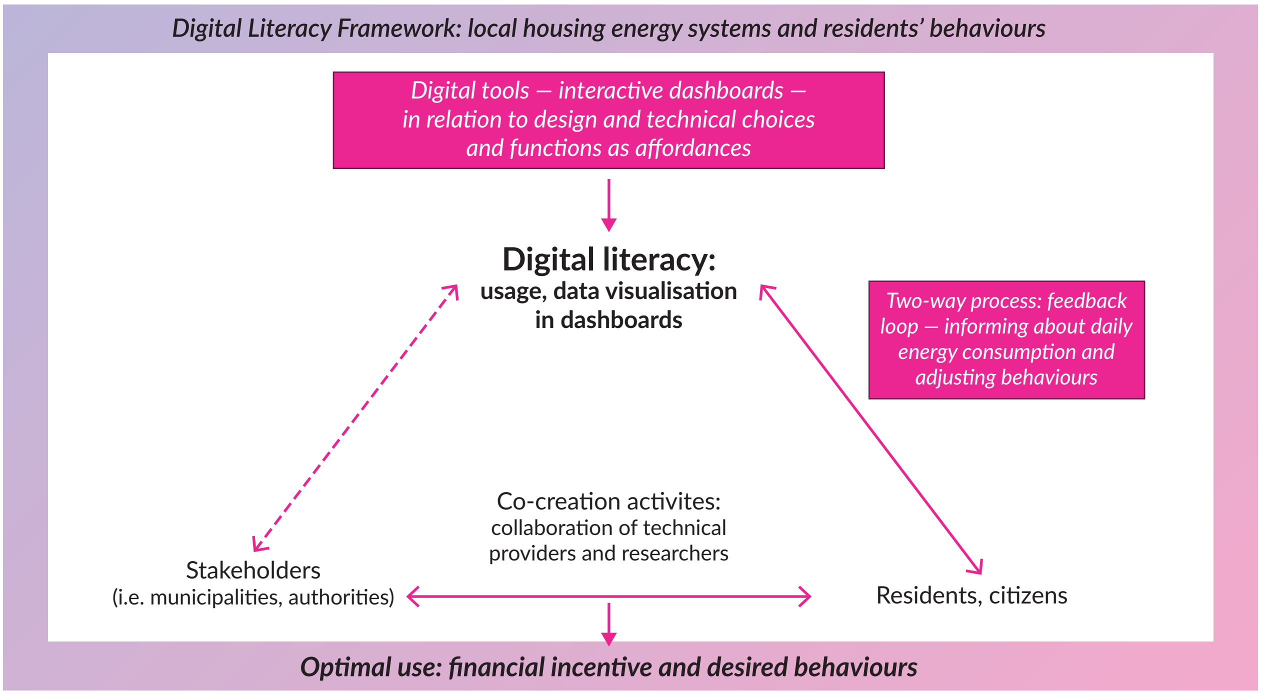

Figure 8. Digital literacy framework—adaptation to local housing energy systems and resident behaviours.

While Figure 1 is based on the theoretical foundations, Figure 8 is the adaptation of the framework to the use cases. The adaptation represents the optimal use of the local housing energy system, the role of digital literacy in relation to desired beahviours. By showing energy consumption and the implicit financial incentives through data visualisations (see Figure 8), this process encourages collaboration, informed decision-making, and behaviour change to optimise energy use in housing systems. The two-way process (right arrow) implies that a feedback loop is established between residents and the system, in which the degree of digital literacy allows the residents to be informed about their energy consumption patterns through dashboards, which helps them adjust their behaviours in real-time. The vectorial interaction between stakeholders ↔ residents indicates that stakeholders receive feedback from residents, which can guide improvements in design and functionality. This interaction is supported by common levels of digital literacy in the communities, enabling both sides to communicate effectively using data insights. It is logical to argue that if a co-creation approach is adopted, digital literacy might be increased after the collaborative activities. From an analytical perspective, the various degrees of digital literacy are potentially conceived as a social struggle over access to and control of space, place, territory, region, and resources. Co-creation activities are intended as a privilege in terms of resources from the stakeholders of money and time (e.g., participation fatigue), to organise a session of co-creation, one need to find a space, a facilitator, etc. thus it requires both effort from the whole set of actors. From the comparative analysis, dilemmas in terms of urban planning emerged. More resources to organise co-creation activities and fewer time constraints due to Covid-19 would have been beneficial for the Almelo case. However, it is quite challenging to assess how the Aardehuis project can inform improvements in projects like the Oude Weverij. The real question is how technology can be useful when the involved users are not interested in the collective use of it. Finally, results included in the framework demonstrate that to ensure optimal use, financial incentives and desired behaviours act as motivating factors, in which the incentives encourage both stakeholders and residents to adopt and use the tools effectively.

6. Conclusion

After the discussion of similarities and disparities between the two cases located in the Dutch context, it is clear what the challenges of small-scale projects using interactive dashboards are. The relationship between the digitalisation process of house energy systems and the context/community/scale is co-shaped by the level of digital literacy and co-creation activities organised between stakeholders involved in this process. The scale in particular is crucial in determining the level of trust and cohesion during the digitalisation process; namely, local and rural scales seem ideal for a more effective impact. The digitalisation process entails an individual set of technical skills and a degree of digital literacy of the inhabitants who are expected to comprehend and choose technical affordances—monitoring and steering tools—like dashboards and different data visualisation techniques. The degree of digital literacy is a pivotal factor in shaping socio-economic dynamics within decentralised systems applied to individual households. Overall, it determines access to opportunities, economic outcomes, and community engagement. However, it is essential to recognise that digital literacy operates within a broader context of socio-economic factors, including income inequality, housing affordability, social dynamics, and consequent spatial unevenness. By recognising the interrelation of co-creation activities, digital literacy, and socio-economic dynamics, policymakers and stakeholders can work towards creating a more equitable and inclusive pattern, which should be specific for each case: Digitalisation for whom and for which purposes?

Future research agendas might consider charting new directions for urban-ecological relations guided by alternative ways of knowing challenges and obstacles. There is an urgent need to steer away from the current emphasis on smart technologies and decentralised systems without considering behavioural factors, co-creation activities, and collective learning, as well as the degree of digital literacy within different communities. Moving into a state-of-the-art sustainable house is, for a citizen, "like going from a horse carriage to a Tesla, to cite a colleague in the project" (Riezebos, 2024) in terms of digital literacy—and definitely, if all the co-creation activities would have been conducted in Almelo, the tenants would have been more engaged. To overcome these challenges, there are a few contingencies to consider. It is unmistakable that when there is a community behind any project of technological implementation, the individual degree of digital literacy can be transformed into a common ground and therefore into a digital commons which helps to solve problems in a collective way. This might be a call to reclaim a more collective and public use of technology (Terranova, 2022) to resist big-tech and individualisation forces proclaimed by Californian ideology. To conclude, it must be kept in mind that not everyone has the economic privilege and time to attend participatory activities or co-creation practices. Instead, there is an urgent need to understand the degree of digital literacy in different communities and its consequential spatial uneveness.

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Acknowledgments

The authors thank the reviewers and the academic editors for their precious comments on how to improve the article, as well as the partners, researchers, experts, and inhabitants of the two use cases for being so generous in terms of time and information given.

Funding

The authors gratefully acknowledge the support of the project SERENE, which received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957682. This article reflects only the authors' views, and the funding agencies and the European Commission are not responsible for any use that may be made of the information it contains. The authors also acknowledge the support of the RVO project Het Indië-terrein: Een slimme buurtbatterij in de oude Weverij, as well as the granted access to primary data collection in the two selected use cases. This article benefits from the authors' direct involvement in both projects. Publication of this article in open access was made possible through the institutional membership agreement between the University of Twente and Cogitatio Press.

Conflict of Interests

The authors declare no conflict of interests.

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ISSN: 2183-7635

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