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Towards Green(er) Cities: Contextualizing Green Benefits for Urban Spaces and Contemporary Societies

Editor

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Editorial

Towards Green(er) Cities: Contextualizing Green Benefits for Urban Spaces and Contemporary Societies

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Abstract

There is an expanding understanding of the value and critical need for green(er) cities. It comes at a time when green spaces are depleting on a global scale, in order for cities to host the majority of the world's population. The contest between diverse land-uses is inflating the pressure on already strained resources, intensifying the growing carbon footprint and impairing water quality, and compromising health and overall quality of life. Soon our cities will be far removed from the safe, clean, and liveable environments, as envisioned in planning theory, if we continue with business-as-usual. There is an increasing scientific appreciation of the interrelated role of green land-uses, the value of our environment and its related ecosystem services, which acts as catalyst to realise the objectives of broader sustainability. Although literature is clear on the importance, role, benefits, and impact of green(er) cities, the realisation of the greening initiatives in practice is still limited, and more should be done to embed green(er) thinking as part of mainstream urban planning. Urban spatial transformation is needed to reclaim nature for cities and to enhance the direct and indirect benefits that nature provides to contemporary societies. This thematic issue considered various trans-disciplinary approaches to provide a way forward in the quest of prioritising the notion of green(er) cities, while drawing on a range of evidence-led initiatives.

Keywords

contemporary societies; future cities; green benefits; sustainability; urban spaces

Issue

This editorial is part of the issue "Towards Green(er) Cities: Contextualizing Green Benefits for Urban Spaces and Contemporary Societies" edited by Juaneé Cilliers (University of Technology Sydney, Australia).

1. The Changing Urban Landscape and Interrelated Role and Value of Nature

The environment is changing at a rapid pace, largely ascribed to population growth and increasing urbanisation. As the majority of the global population now resides in the urban landscape, cities have become a central nexus in the relationship between people and nature. While global spatial policies aim to manage urban growth to ensure that the benefits of urbanisation are fully shared and inclusive, most spatial initiatives focus on access to infrastructure and social services for all, with a less significant focus on green spaces provision within the urban fabric. The provision of urban green spaces is well researched and captured in literature, with results pointing to a range of supplementary ecosystem services supporting humanity, including provisioning, regulating, supporting, and cultural services. Concurrently, various case studies have also concluded on the severe impact pertaining to the lack of green spaces in cities and neighbourhoods, often triggering additional negative impacts relating to the intensified urban heat island effect, increased energy consumption, impaired water quality, and ultimately compromised human health and comfort. Recently, the scholarly interest in urban green spaces has peaked with the recognition that urban green space holds the potential to turn the situation around and to enhance urban quality of life. Likewise, research has proven that green spaces and associated green infrastructure planning approaches have the potential to strengthen the social-ecological resilience of cities. There is a new reassessment of what landscapes should be in terms of form and function, and despite the growing scholarly discourse, the realisation of green(er) cities in practice is still limited, often approached in an ad hoc manner, and frequently side-lined as urbanisation causes land use change and conflict. Trans-disciplinary approaches and evidence-led initiatives that are included in this thematic issue can provide insights and a possible way forward to position and articulate green(er) cities, as it contextualizes green benefits for urban spaces and contemporary societies.

2. Towards Urban Spatial Transformation and Green(er) Cities

Urban spatial transformation is needed in quest towards green(er) cities. The first article in this thematic issue states how cities often rely on short-term incremental solutions to reduce urban infrastructure's vulnerability to natural disasters but emphasised that the focus should rather be on longer-term transformative solutions and collective urban green infrastructure solutions. While incremental urban planning and design approaches such as urban greening, water-sensitive planning, disaster risk management, community resilience, and climate-resilient building and infrastructure contribute to the notion of sustainability, it is the longer-term transformative designs and urban spatial innovations which are required to make our cities more climate-proof and resilient.

The second article further emphasises the importance and role of vegetation in climate adaptability, stating that climate-responsive urban design is dependent on urban form, urban structures, and the role of greenery within these settings. Climate adaptivity however calls for the development of normative criteria on how to design the forms of urban settings which integrate vegetation as part of mainstream spatial planning.

The third contribution agrees that the current approaches to make cities green(er) or more sustainable are still linear and insufficient to deal with the growing urban challenges but recognises that bioconvections can be considered the enablers of regenerative circularity. The article illustrates that the adoption of regenerative and circular lenses for the built environment may foster a more holistic development based on "what is good" rather than "what is less bad." The article explores a vision of regenerative and circular development based on five principles: (1) positive impact; (2) systemic and life cycle thinking; (3) circular and just use of resources; (4) bio-inspirations; and (5) inclusive, equitable, and safe urban spaces.

The fourth article explores the concept of urban green infrastructure and the importance of context-specific, user-centred design. Although green infrastructure is known for its potential to mitigate the adverse effects of urban density and the heat island effect, enhancing the ecological and social resilience of cities and their inhabitants, there still seems to be a subjective evaluation of urban green infrastructure. The article explores the contextual, psychological, and social factors which influence people's subjective evaluation of urban green infrastructure, density, and heat stress, and made various planning proposals for effective, context-specific, user-centred design which are set to increase the social and health benefits linked to urban green infrastructure.

Article five explores the economic side of urban green infrastructure, focussing on the economic valuation of urban green spaces. Even though theory underpins the benefits of urban green spaces in delivering ecosystem services and potential economic benefits such as increases in proximate residential property prices, the article identifies that specific planning and design interventions would be needed to underscore the need to protect and curate features that encourage willingness to pay for urban green space proximity.

Similar findings are presented in the sixth article which recommended to reconnect society with nature in cities through close-to-nature design of urban green space. Close-to-nature heuristic design principles are proposed to support future urban green infrastructure, to deliver multiple ecosystem services and delivery on broader resilience objectives. These proposals are based on the investigation into the Essex Climate Action Plan in the UK and its approach in utilising green infrastructure to combat climate change and generate thermal comfort zones in cities.

The seventh article analysed visual landscapes from rural Poland to conclude on the harmonizing spatial alterations that are needed in rural communes.

Article eight explored options to co-create a green(er) future in Dublin and outlined a methodological approach towards community-led greening strategies, which are both inclusive and policy-driven. A process map is proposed that could enable community, local authorities, and other policymakers to engage with community-led coalitions in quest to develop more inclusive and appropriate urban greening strategies.

The ninth article investigated a different "community of practice approach" to plan water sensitive cities in South Africa.

The tenth and final article concludes this thematic issue by illustrating the importance of the interface between urban planning and urban ecology and how the current gap between these disciplines can be minimized.

3. Conclusion

Based on the findings of the articles included in this thematic issue, it is evident that ecological considerations should be an integral part of the thinking and decision-making processes to guide future city planning. Contextualizing green benefits for urban spaces and contemporary societies will imply a shift towards resilience thinking in planning, where spatial planning adequately responds to the increasing economic, social, and environmental vulnerabilities in cities, and halt the rapid depletion of natural resources and environmental degradation. It calls upon a systems approach to planning contemporary urban landscapes. Transdisciplinary planning would be key to co-create the green(er) cities of the future.

Conflict of Interests

The author declares no conflict of interests.

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Juaneé Cilliers is head of the School of Built Environment, and professor of urban planning at the Faculty of Design, Architecture and Building at the University of Technology Sydney (Australia). She has professional registrations from both the South African Council for Planners (SACPLAN) and the Planning Institute of Australia (PIA). She is currently appointed as extraordinary professor of planning at the North-West University (South Africa), the chair of the Women in Planning Network of the Commonwealth Association of Planners (https://www.commonwealth-planners.org/cwip-network), and advisor to the board of the International Society of City and Regional Planners (ISOCARP).

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Commentary

From Urban Façade to Green Foundation: Re-Imagining the Garden City to Manage Climate Risks

Rob Swart [1,]*, Wim Timmermans [1], Jos Jonkhof [1] and Hasse Goosen [2]

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Abstract
Climate risk management evolves rapidly from one additional challenge for urban planning into a radical driver of urban development. In addition to fundamental changes in urban planning to increase long-term resilience, the creation of new opportunities for sustainable transformation is imperative. While urban planners increasingly add climate risks to their menu, implementation of effective action is lagging. To reduce urban infrastructure's vulnerability to heat and flooding, cities often rely on short-term incremental adjustments rather than considering longer-term transformative solutions. The transdisciplinary co-development of inspiring urban visions with local stakeholders over timescales of decades or more, can provide an appealing prospect of the city we desire—a city that is attractive to live and work in, and simultaneously resilient to climate hazards. Taking an historic perspective, we argue that re-imagining historical urban planning concepts, such as the late 19th-century garden city until early 21st century urban greening through nature-based solutions, is a pertinent example of how climate risk management can be combined with a wide-range of socio-economic and environmental goals. Climate knowledge has expanded rapidly over the last decades. However, climate experts mainly focus on the refinement of and access to observations and model results, rather than on translating their knowledge effectively to meet today's urban planning needs. In this commentary we discuss how the two associated areas (urban planning and climate expertise) should be more fully integrated to address today's long-term challenges effectively.

Keywords
climate adaptation; climate services; garden city; historical urban planning context; nature-based solutions; resilience; urban transformation

Issue
This commentary is part of the issue "Towards Green(er) Cities: Contextualizing Green Benefits for Urban Spaces and Contemporary Societies" edited by Juaneé Cilliers (University of Technology Sydney, Australia).

1. Introduction: Climate Change Response and the Reimagination of the Garden City

In this commentary we highlight the pervasive impact that climate change will have on city design and the potential of greening as a transformative response. More than a century ago, the publication "Garden Cities of Tomorrow" (Howard, 1902) signalled the start of the urban greening movement. Over time, many other new city planning paradigms emerged and faded. Now, new challenges give a boost to the reimagination of green cities. Continuing global urbanisation is projected to add another 2.5 billion people to urban areas by 2050 (UN, 2018), with increasing demand for additional land by a factor of 1.8–5.9 by 2100 (Gao & O'Neill, 2020). "The modern-city model that took hold globally in the twentieth century has outlived its usefulness. It cannot solve the problems it helped to create—especially global warming" (Plastrik & Cleveland, 2018, p. xi). Below, we elaborate the ramifications for urban planners and climate experts.

2. Shifting Urban Planning Paradigms

Urban planning has a long history of new priorities and perspectives (Figure 1). In the context of this thematic issue, we take the garden city concept (Howard, 1902) as starting point, a response to the unhealthy and overcrowded cities of the times, combining the advantages of town and countryside to provide a better alternative for the working class (Kohout & Kopp, 2020). Mumford (1938) suggested the establishment of a regional "bio-technic'' order which would renew mankind's association with nature. In the same period, Le Corbusier started the innovative movement of the functional city as a laboratory for new urban concepts to transform the urban environment to fit modern times (van Es et al., 2014). Car use infrastructure had to be combined with the need for large numbers of dwellings as well as green space, clean air, and proximity of citizens to natural spaces. After WWII, the emphasis of urban planning shifted further away from nature towards post-war reconstruction, such as building adequate housing and the expansion of private car use, with accessibility a top priority for urban (infra-)structural developments. From the 1960s, economic growth put its mark on rapidly growing cities as centres of business and technological innovation, triggering the development of concepts such as organic community-based urban development (Jacobs, 1961), ecological urban design (McHarg, 1969), cities as complex systems of interrelated—including environmental—components (von Bertalanffy, 1969), and urban metabolism (Coelho & Ruth, 2006).

Towards the 1980s, the negative consequences of economic growth, such as increasing air and water pollution, came to the fore. The 1992 Earth Summit gave new impetus to reduce the environmental impact of cities and promote sustainable development. Municipal governments in industrialised countries adopted climate change as a policy issue, initially mainly focusing on mitigation by proposing energy- or carbon-neutral, or climate-smart, cities. When climate hazards were projected to increase and urban developments had already increased exposure to these hazards in many places, adaptation plans started to promote resilient or climate-proof cities. A plethora of concepts addressed the rapidly emerging challenges, including future cities, eco cities, smart cities, intelligent cities, sustainable cities, compact cities, liveable cities, digital cities, innovative cities, green cities, and green urbanism, to name a few (e.g., Moir et al., 2014). City networks were established to exchange information on the experience of implementing these concepts.

3. From Climate Science to Urban Climate Services

When Howard introduced the garden city concept, he may have been unaware that around the same time in Sweden, Arrhenius (1897) predicted that fossil fuel combustion with associated CO_2 emissions would lead to global warming. It would take almost a century before the two issues became profoundly intertwined (Figure 1). Until well after WWII, climate science focused mostly on natural changes. However, from the 1970s, improved modelling capabilities suggested that the planet would warm as a result of human activities. The first scientific assessment report of the Intergovernmental Panel on Climate Change in 1990 triggered the establishment of the United Nations Framework Convention on Climate Change in 1992. At that time, the prevailing hope and

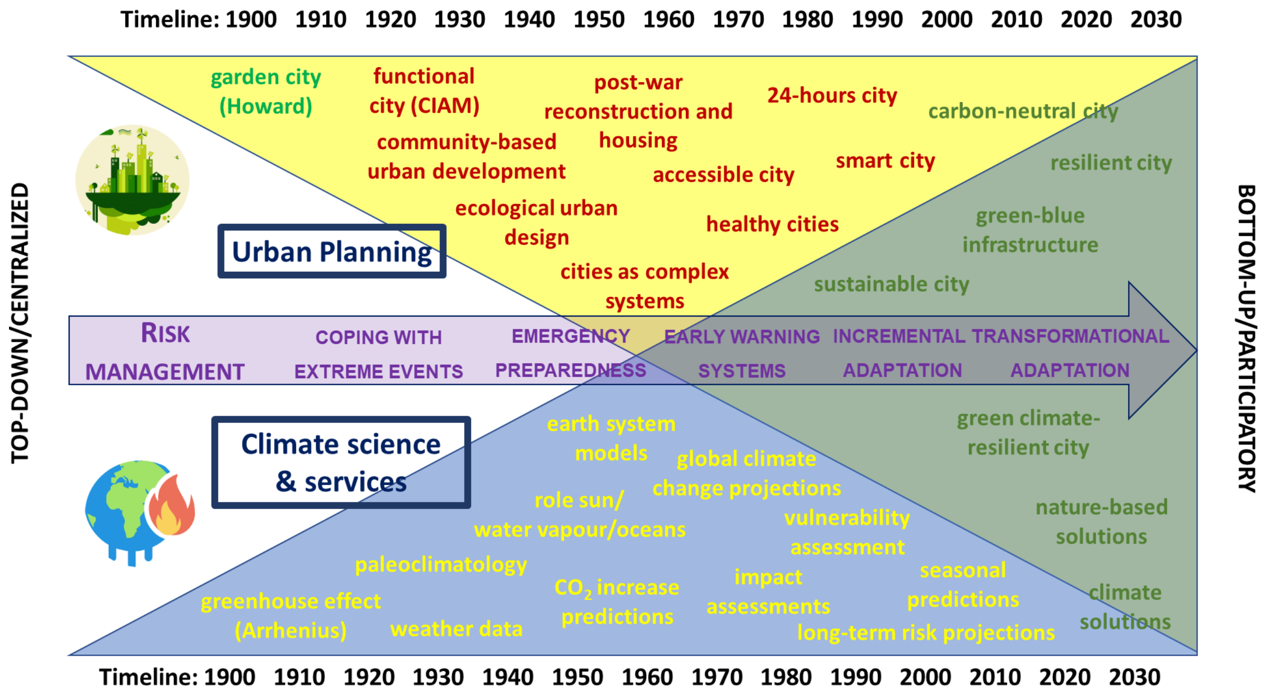

Figure 1. Integrating urban planning concepts, climate science, and action over time.

belief was that climate change impacts could largely be prevented, hence the initial emphasis on mitigation. Simultaneously, knowledge about climate change impacts expanded, partly as a result of improved modelling capabilities in important areas such as hydrology and ecology. As actual climate impacts became more and more visible and the hopes for quick mitigation evaporated, adaptation came to the fore. To support adaptation among those vulnerable to climate impacts, the concept of "climate services" was introduced in the last decades of the 20th century (Brasseur & Gallardo, 2016; Zillman, 2009). These services were established to improve access to weather and climate data, presenting them in ways suitable for users with more limited knowledge and skills. In Europe, in particular, the scope of climate services was expanded to include the improvement of climate resiliency across the continent as well as to generate jobs. Urban planners are a major target and user group for these climate services.

4. From Incremental Climate Adaptation to Resilient Urban Transformation

Since the turn of the century, urban planners and climate experts cautiously started to connect. However, we argue that the urgency and pervasiveness of climate change requires integration between these two groups to be accelerated and deepened (Figure 1). Four challenges need to be addressed. Firstly, *systemic change is needed to advance urban planning and development towards longer-term transformation*. Arguably, in many cities, the climate change response is increasingly connected to other environmental, social, and economic challenges such as globalisation, ageing, technological developments, geo-political change, mobility, ecological risks, resource limitations, inequality, social tensions, and changing institutional and governance frameworks (Moir et al., 2014). However, merely connecting is becoming insufficient: Climate change forces urban planning to transform from addressing climate risks within the constraints of existing urban systems towards redesigning the urban system to address long-term challenges, in particular climate change—from "function follows system" to "system follows function."

Secondly, *the unfolding of climate change requires extending the time and space horizons of urban agendas*. Considering the possible risks of climate change mainly in terms of short- to medium-term timescales, incremental measures often still prevail: Quick-win measures that reduce risks without changing overall city design. Examples include raising dykes or other flood protection infrastructure, enlarging drainage systems, or refurbishing buildings for cooling. These measures are often insufficient to avoid long-term impacts and may even hinder effective transformative solutions. In addition, climate change requires expanding the spatial scope of planning, from the level of neighbourhoods to the scale of the city and its hinterland, which is important for the sustainable availability of resources such as water and food. Views on the relationship between cities and the green open space around them have fluctuated over time. Climate change also forces us to reconsider this relationship. Elmqvist et al. (2021) argue that to boost sustainability, new urban challenges such as climate change require rescaling diversity (e.g., food supply, blue-green infrastructure), enhancing urban-rural connectivity and new cross-scale interactions, and better management of increasing complexity.

Thirdly, *the framing of climate change and the associated planning process should be reshaped to create sustainable solutions.* The (positive) creation of opportunities can be a more effective climate response perspective than a narrow (negative) focus on risk management. Climate-resiliency is often addressed in a defensive way, such as "bouncing back" in order to maintain a city's basic functions and structures in the face of climate risks. "Bouncing forward" may be a more positive approach, transforming a city's economic, social, and political functions and structures to be better prepared for a future in which adaptive and participatory management allows navigation towards an attractive and resilient city (Plastrik & Cleveland, 2018). Urban planning that builds cities' resilience to new weather conditions can transform these spaces into powerful instruments for sustainable development (Climate-Fit City, 2018). This requires innovative urban visioning, using transdisciplinary foresight methods and tools (McPhearson et al., 2017), and the evolution from an initially expert-driven, centralised, top-down urban planning process to a participatory, decentralised, bottom-up process with the engagement of a wide variety of stakeholders (Figure 1).

Fourthly, *this transdisciplinarity requires climate services to be widened and transformed, integrating them with long-term urban planning.* Climate experts have important knowledge that can support urban transformation beyond providing climate data. They can help inform choices for urban investments such as the location of new urban areas and infrastructure (e.g., flood risk); the design of buildings, neighbourhoods, and green spaces (e.g., temperature implications of specific designs of buildings and city districts and climate-sensitivity of plants and trees); and the connectivity between urban areas and their hinterland. Process-wise, in order to meet their potential, climate services would have to develop from "science-driven and user-informed" to "user-driven and science-informed" (Street, 2016).

5. From Façade to Foundation: Urban Greening and Resilient City Transformation

If the above challenges are met, to what kind of urban solutions may this lead? While it may not be the only solution, we advance pervasive urban greening as a key avenue for the design of a sustainable, inclusive, economically successful, climate-fit, and attractive urban environment. Many concepts have been proposed, including ecological engineering, urban forestry, ecosystem-based adaptation, green/blue infrastructure, renaturing cities, and green urbanism. Often, these concepts highlight one or more themes (Escobedo et al., 2019), such as biodiversity, mitigation (carbon-sequestration), or leisure. Nature-based solutions are a recent addition to these concepts that integrate environmental, social, and economic objectives in a comprehensive manner. They are inspired and supported by nature, but also address cost-effectiveness by simultaneously providing environmental, social, and economic benefits and helping to build resilience (Dorst et al., 2019; EC, 2015). Different forms of (peri-)urban agriculture via gardens and farms (Smit et al., 1996) should also be included explicitly in the design of transformed cities as they address various issues related to climate change, encompassing environmental, social, and economic benefits.

As summarised above, over the course of more than a century many urban planning concepts representing different foci and perspectives have been proposed. Nature-based solutions connect to many of these concepts which are often still relevant today and worth revisiting, starting with, but not limited to, the garden city. This short commentary does not do justice to all possible approaches, and eventual choices will necessarily depend on local circumstances and priorities.

To conclude, we synthesise four recommendations from the above:

- *Long-term climate change should be seen as a guiding determinant of future urban design rather than just one among many boundary conditions for urban planners.* Both preparedness for extreme weather events and incremental measures to adapt to a changing climate can often be accommodated within the existing urban structure. However, realising a climate-resilient city for the longer term changes the rules of the game.
- *Climate change requires an integrated, transdisciplinary, long-term approach to planning, from the scale of buildings and neighbourhoods to the peri-urban region.* Climate change intersects with many other urban challenges, including citizen housing, health, inequality, employment, accessibility, leisure, greening, and technological development. As climate change also affects the provision of external resources and local risks are affected by climate impacts in the urban hinterland, climate change does not only require expansion of time but also spatial horizons.
- *Climate change provides opportunities for positive urban visions and designs*. Climate change does not necessarily have to be seen solely as a threat to urban development but can also be viewed as an opportunity for transformational change that addresses other objectives. This requires the co-development of positive visions for attractive, safe, and thriving future cities by citizens, local companies, urban planners, ecologists, and climate service providers. In particular, the scope of climate services needs to be widened to achieve this vision.
- *Urban greening through nature-based solutions and urban agriculture addresses climate change mitigation and adaptation in addition to multiple other objectives.* Designing urban green infrastructure in a sustainable and effective fashion requires an understanding of the future climate and its implications for mitigation and adaptation. Climate change suggests reinventing the garden city in novel ways, with nature-based solutions and urban agriculture as key integrating concepts.

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Conflict of Interests

The authors declare no conflict of interests.

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Rob Swart worked between research and policy in the areas of environment, climate change, and sustainable development for more than four decades. He graduated as an environmental engineer from Delft University of Technology in 1980 and worked, inter alia, for the Pan American Health Organization, the Netherlands Environmental Assessment Agency, the Intergovernmental Panel on Climate Change, the European Environment Agency, and Wageningen Environmental Research. After retiring in 2020 he remained associated with the latter institution. A core theme in his work is the connection between climate change response and broader sustainability themes.

Wim Timmermans worked for 15 years as a sustainability policymaker for Dutch cities and 20 years as a senior researcher (WUR) and associate professor (Van Hall-Larenstein University of Applied Sciences) on green urbanism, sustainable planning, and climate adaptation. He holds a degree in innovative land use and green planning from the University of Santiago de Compostela. He was active in his local town council and actively follows local politics as a journalist. His experience enables him to reflect on urban climate adaption from science, policy, politics, and people's perspectives.

Jos Jonkhof, a sustainable urban planning engineer from Delft University of Technology, worked at the Dutch Ministry of Housing, Urban Planning and Environment in the 1980s and 1990s and as researcher and conceptual designer at Wageningen University & Research from 2000. After retirement, he was involved in conceptual design projects for municipalities, regional, and national water authorities. From 2012–2016, he contributed to the French governmental Research Programme Land Transport Infrastructures, Ecosystems and Landscapes. He focuses on the relationship between conceptual planning development and the ecology of knowledge in research and planning.

Hasse Goosen (PhD), as director of Climate Adaptation Services Foundation, has supported numerous governments at different administrative levels in the development of adaptation plans and strategies. Hasse played a key role in the Dutch Delta Program Spatial Adaptation, helping with the introduction of the stress test and climate atelier approach in the Netherlands and organising dozens of climate workshops with various municipalities, provinces, and water authorities. Hasse has experience in the development and application of planning and decision support tools and techniques for adaptation to climate change.

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Article

The Role of Vegetation in Climate Adaptability: Case Studies of Lodz and Warsaw

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Abstract
The threats that arise from climate change and their associated economic, social, and environmental impacts are leading to the transformation of the spatial structures of cities. The growing demand for climate adaptability calls for the development of normative criteria for the design of forms of urban settings that integrate vegetation. Climate-responsive urban design reacts to the challenges of urban physics, which depend heavily on the forms of urban structures and the role of greenery. This method includes research on vegetation indexes and their impact on urban regulatory functions. The goal is to propose a comprehensive framework for assessing the functioning of urban public space, which considers the role and maintenance of green infrastructure. The intersection with the subject matter of analytical urban morphology is evident, in terms of the resolution of the urban fabric and its transformations over time. The framework of climate-responsive urban design also covers examining the parameters of surrounding built structures, such as the floor area ratio, the building coverage ratio, and building heights. In particular, the requirements of climate adaptation have an impact on the design of outdoor spaces in cities. In this article, we apply the selected methods that contribute to the climate-responsive urban design model to recommend the transformations of two urban nodes, in Lodz and Warsaw (Poland). Our goal is to indicate the future form of nodal public spaces with a focus on the needs of urban greenery, and to determine indicators for the local climate zone. After an initial literature review, we discuss a number of available indicators from the perspective of how they might contribute to determine the environmental conditions. We focus on urban water cycle, the requirement of trees for water, and insolation conditions.

Keywords
climate adaptability; ecosystem services; green infrastructure; Lodz; urban design; urban vegetation; Warsaw

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1. Introduction

Cities are complex social-ecological systems that engage numerous stakeholders and embrace diverse ecological processes (Alberti, 2008; Andersson et al., 2014; Berkes & Folke, 2000). While the need for climate adaptation in cities has been broadly recognised (European Commission, 2021; European Environment Agency, 2016; Mayor of London, 2018; Reusswig et al., 2016), there is still the question of how to engage concerned actors in the desired stewardship. We believe that improved understanding of regulatory ecosystem services would help address this issue. The three-fold nature of social-ecological systems in cities includes infrastructures, institutions, and perceptions (Andersson et al., 2019). In this article, we address the first of these elements, urban infrastructures, in the quest for a normative framework for design purposes. We further divide this category into so-called grey infrastructure (buildings, parcels, streets, and squares) and green infrastructure (GI, various forms of vegetation; Marcus et al., 2019). The first group remains subject to urban morphology research (Caniggia & Maffei, 2001; Conzen, 1960; Oliveira, 2016), and the second belongs to the scope of urban ecology (Alberti, 2008; Andersson, 2006; Colding et al., 2013; Forman & Godron, 1986). Both the urban fabric and GI impact the urban microclimate. Cities as man-made habitats are influenced by geographical factors, including both abiotic and biotic factors, but also the intensity and range of human activities.

The ecological processes in cities are not confined to a single ecosystem; instead, cities are a mosaic of interconnected ecosystems that interact. Spatial patterns affect them to the point that they can be assumed based on the distribution and structural configuration (Andersson, 2006). In addition to the mutual relationships and spatial links, the analysis should consider the panarchy of interconnected habitats, which embraces multiple scales. In urban cores, new interventions in woodlands usually belong to the category of "functional greening" with planted tree stands in green spaces (Kowarik, 2005, p. 9). Therefore, to design successful urban climate adaptation measures integrating vegetation, it is first necessary to understand the processes between the urban fabric and GI. Then, we should trace the relationships between the elements of GI within the social-ecological urban system.

In this article, we analyse two urban spaces located in two major Polish cities: Warsaw and Lodz. We consider both the elements of their infrastructures and their interrelations. In the next section, we present the research background, followed by the methodology and the case study characteristics. We then apply the selected methods to both sites and discuss the results. The final section includes recommendations and proposes future research paths.

2. Research Background

Climate change adaptation has attracted much attention from researchers in recent years. Most research so far relates to evaluating ecosystem services on the scale of a region (Carter et al., 2015; Haase et al., 2012; Niemelä et al., 2010; Schirru et al., 2019) or a city (Gill et al., 2007; Liu & Russo, 2021). There are fewer studies that address the scale of the neighbourhood. There are numerous reasons for this discrepancy. First of all, the natural conditions are challenging to parameterise, due to the many variables. The local conditions include, among others, topography, soil structure, climate, and anthropomorphic transformations, such as soil sealing and existing biodiversity. The plant forms range from simple lawns to complex systems of low vegetation, such as lawns, ground cover, perennials, and bulbous plants, from annuals and biennials to shrubs, tall trees, and creepers. All these elements are affected by their immediate and broader context. There are also few studies considering the relations between different types of infrastructure in a comprehensive manner. Most research that deals with interrelations between urban spaces and green areas addresses a single theme, such as urban heat island (UHI; Armson et al., 2012; Kannamma & Sundaram, 2015; Norton et al., 2015; Shashua-Bar & Hoffman, 2003). The urban or metropolitan context is evident in studies on the role of greenways as connecting elements for the growth and preservation of biodiversity (Alberti, 2008; Bryant, 2006). Other phenomena discussed above also need to be included in a system and panarchy approach.

In this article, we refer to the Millennium Ecosystem Assessment (2005), which provides a commonly recognised framework to evaluate the benefits of GI. GI contributes to the social-ecological system, the design of which needs to be comprehensively understood (Redman et al., 2004). The scheme includes four categories of ecosystem services: supporting, provisioning, regulating, and cultural. Climate change adaptation, which is the topic of this article, deals primarily with regulatory services, including, among others, water retention and UHI reduction. The concept of normative guidelines for designing urban settings and integrating vegetation has attracted the interest of researchers before (McDonald et al., 2007; Whitford et al., 2001). Climate-responsive urban design addresses the interplay of urban physics and ecosystem challenges, which depend on the forms of urban structures and the role of fauna and flora. Studies that merge these two topics are still rare. For example, Marcus et al. (2019) recommend a combined socio-ecological morphology. They propose two systems of overlapping patches representing social entities: built structures and ecological structures. We focus on the regulatory functions of urban ecosystems, which we attempt to link with some characteristics of built structures.

3. Methodology

The impact of vegetation on urban settings was assessed based on several factors. Each specific feature has its distinctive methodology of assessment defined in the subject literature. Table 1 presents the primary regulatory ecosystem functions associated with the characteristics of GI. The relationships defined in all three tables were defined based on the initial literature review, which led to the selection of a number of indicators that describe urban vegetation (Table 1), types of vegetation (Table 2), and forms of urban structures (Table 3). For each of these elements, we determined how they affect local environmental conditions. The focus of the current article is on developing proper conditions for

Table 1. Parameters of urban vegetation in relation to the role of greenery as a factor affecting comfort and climate adaptability.

	Parameter Describing Urban Vegetation						
Ecosystem Services	Leaf Area Index	Tree Canopy Cover/Tree Roots Extent	Normalised Retention/ Infiltration Index	Difference Vegetation Index	Carbon Storage Index	Biological Diversity Index	Indigenous Species Index
1. Cooling of UHI	X[1]	X[2]					
2. Preventing water cumulation during flash floods	X[3]	X	X	X[4]			
3. Water retention and infiltration: draft prevention	X[5]	X[6]	X[6]	X[4]			
4. Strong wind prevention	X	X					
5. Air pollution prevention	X[7]	X[8]				X[9]	
6. Rainwater cleansing	X	X[6]	X	X[4]			
7. Soil pollution prevention	X[10]	X[11]		X		X[9]	
8. Prevention of organic pollutants and bacteria	X[12]	X[13]					
9. Urban vegetation resilience, adjustment to urban conditions	X[14]	X[15]	X[16]	X	X	X[9]	X[17]

Notes: [1] Pace et al. (2021); [2] Köhler and Kaiser (2019); Loughner et al. (2012); Ziter et al. (2019); [3] Jalolen et al. (2013); Yang et al. (2019); [4] Szczepanowska and Sitarski (2015); [5] Simic et al. (2004); Yang et al. (2019); [6] Law and Hanson (2016); [7] Janhäll, (2015); [8] Badach et al. (2020); Barwise and Kumar (2020); Nowak (2002); [9] Gaj (2012); Nowak et al. (2013); [10] Nascimento et al. (2016); [11] Pérez-Suárez et al. (2008); [12] Wei et al. (2017); [13] Gong et al. (2021); Nakamura et al. (2017); [14] Wu and Liang (2020); [15] Hale et al. (2015); [16] Gustafsson et al. (2020); [17] Oliver et al. (2015); Rowntree and Nowak (1991).

urban greening interventions to achieve the highest performance in terms of ecosystem regulatory functions.

Table 2 relates types of urban vegetation to their regulatory ecosystem functions. The roles of various types of vegetation differ. To successfully design urban spaces, we should be able to take this into account. Table 3 shows the impacts of urban forms on the local environment, including vegetation. These aspects are rarely considered in urban ecosystem research. However, the analysis of the potential impact of various features of urban structures on the physical conditions of urban space proves their essential role.

Based on the above analyses, we selected those features of the urban environment which are essential for shaping climate adaptability. In the following sections, we discuss some of the aspects of the parameters listed above, which we will then use in the case study analysis.

3.1. Biodiversity

Designers usually understand biodiversity as species diversity, which translates into a variety of taxonomic units. In ecological research it is not always a positive parameter, because of the likely presence of alien and invasive species which, in turn, can only be assessed in the context of a given place. For example, suppose native species in a given place have challenging conditions for vegetation due to anthropogenic transformations, and foreign and even invasive species cope in this place. In such cases, the negative assessment of invasive taxa will not be unambiguous. Moreover, biodiversity research emphasises the potential for the emergence of spontaneous vegetation. It involves the openness of the designed compositions to the "adoption" of new species and natural processes. The species composition translates into the provided and expected ecosystem services. For example, some plants have phytoremediation abilities (Piotrowska-Niczyporuk & Bajguz, 2013). Studies on the capture of particulate matter by trees in cities show that linden can be one of the most efficient species in this respect (Popek, 2013).

Research on biodiversity uses various, often very complex methods (Kruk, 2014), which are challenging in everyday design practise due to the time required to observe the directions of changes (at least one growing season, and preferably in long-term studies). In addition, biodiversity can be considered at the level of the diversity of taxonomic units (as above), at the level of the gene pool, or, finally, at the scale of entire ecosystems (the latter requires time, a large team, and specialised equipment). Researchers agree that conducting analyses using only one of the methods cannot yield reliable results. The biodiversity taxonomy parameter seems to be the easiest to use in design.

Table 2. Types of vegetation and their role in climate adaptation: + (influence), +/− (relative influence), and − (no influence).

Role	Types of Vegetation						
	Trees		Bushes		Climbers and Ground Covers	Perennials and Herbaceous Plants	Grasses
	Deciduous	Coniferous	Deciduous	Coniferous			
Temperature regulation:							
1. Cooling of UHI [1]	+	+/−	+	+/−	+	+/−	+/−
2. Warming in cold seasons [2]	−	+	−	+	+/−	−	−
3. Resilience to temperature amplitudes and abrupt changes [1]	+/−	+	+/−	+	+/−	+/−	−
Water regulation:							
4. Preventing water runoff and flooding during flash floods [3]	+/−	+/−	+/−	+/−	+/−	+	+
5. Water retention and infiltration: draft prevention [4]	+	+/−	+	+/−	+/−	+	+/−
6. Rainwater cleansing, soil pollution prevention [5]	+	+/−	+	+/−	+	+	−
Air flow regulation [6]:							
7. Strong wind prevention	+	+	+	+	+/−	−	+/−
8. Air pollution prevention [7]	+	+/−	+	+/−	+	+/−	+/−
Others:							
9. Prevention of organic pollutants and bacteria: etheric substances [8]	+/−	+	+/−	+	−	+/−	−
10. Urban vegetation resilience, adjustment to urban conditions [9]	+	+/−	+	+/−	+	+	+/−

Notes: [1] Norton et al. (2015); Szczepanowska and Sitarski (2015); [2] Myint et al. (2015); [3] Jalolen et al. (2013); [4] Simic et al. (2004); Yang et al. (2019); [5] Dierkes et al. (2002); Szczepanowska and Sitarski (2015); [6] Chen et al. (2016); [7] Badach et al. (2020); Barwise and Kumar (2020); Janhäll (2015); Nowak (2002); Szczepanowska and Sitarski (2015); [8] Gong et al. (2021); Nakamura et al. (2017); Wei et al. (2017); [9] Gustafsson et al. (2020); Hale et al. (2015); Oliver et al. (2015); Szczepanowska and Sitarski (2015); Wu and Liang (2020).

Table 3. Features of the physical environment and their role in climate adaptation.

Role	Features of Physical Environment					
	Floor Area Ratio/Building Coverage Ratio	Height of Buildings	Direction vs. Wind Direction	Setback/ Location on the Lot	Floor Materials and Colours	Colours of Facades
Temperature regulation	X	X	X	X	X	X
Water regulation	X		X	X	X	
Air flow regulation	X	X	X	X		
Urban vegetation resilience	X	X	X	X	X	
Physical conditions for social activities	X	X	X	X	X	X

3.2. Carbon Sequestration

Species diversity is not the only parameter. Other features include natural efficiency, i.e., how much oxygen vegetation gives off to the atmosphere and how much it sequesters and builds into carbon tissues (Nowak et al., 2013), and how the area evapotranspires, which translates into microclimatic conditions. It should be noted that increased biodiversity does not equal higher biomass production nor higher CO_2 sequestration (Köhler & Kaiser, 2021; Körner, 2000).

Individual tree species, in various development stages and depending on the growing season (varying leaf sizes), have different effects in the form of coefficients. These can be calculated based on so-called allometric equations of biomass for individual species (Zasada et al., 2008), which vary depending on the species, its geolocation, neighbourhood conditions, etc. (Altanzagas et al., 2019). Zianis et al. (2005) show the extent of the problem, pointing to 188 trees of one species of *Pinus silvestris* with over 50 different patterns. Therefore, it would be necessary for design purposes to average the data for individual species in a given city. Such compilations have been made in the US (Peper et al., 2007). In Poland, pioneering research in this area was conducted by Szczepanowska and Sitarski (2015). Analyses of street trees in Praga Północ show (resulting from American research by, among others, Nowak et al., 1996; Nowak et al., 2013; Peper et al., 2007) a hypothetical sequestration efficiency in the range of between 81 kg CO_2/mature tree/year and 7 kg CO_2/small tree/year, where an average of 25 kg CO_2/tree/year was assumed. We calculated the amount of sequestrated CO_2 using the equation:

$W_{CO_2} = n \times 25$ kg/year, where n is the number of trees and W_{CO_2} is the amount of sequestered CO_2

Knowing the level of CO_2 sequestration, it is possible to calculate the amount of O_2 produced by trees using the formula W_{O_2} [kg/year] = W_{CO_2} [kg/year] × 32/12 (Nowak et al., 2007).

3.3. Normalised Difference Vegetation Index

Another important index is the normalised difference vegetation index (NDVI), which determines the intensity of photosynthesis. NDVI maps are created by municipalities and can provide information about the health of vegetation.

3.4. Rainwater Retention

Rainwater retention is an essential feature for landscaping. Watering using a balance of local water retention and water supplies is desired. We based the calculations on the formula:

$$Q_r = r_{t;n} \times \Psi_m \times \Sigma A$$

where Q_r is the surface runoff, $r_{t;n}$ is the design rain value, Ψ_m is the runoff coefficient—$(\Psi_1 \times A_1 + \Psi_2 \times A_2 + \dots + \Psi_n \times A_n)/\Sigma A$—and ΣA represents the total surface—$\Sigma A = A_1 + A_2 + A_n$. This was based on works by Dreiseitl and Grau (2009), Geiger and Dreiseitl (1999), and Geiger et al. (2010). The following values were adopted for the calculations:

- Design rainfall: 177.1 l/s (for 15 minutes of rain every five years; RetencjaPL, 2020);
- Runoff coefficients (Geiger & Dreiseitl, 1999): For impermeable surfaces $\Psi_1 = 0.90$, for gravel surfaces $\Psi_2 = 0.15$, and for surfaces covered with greenery $\Psi_3 = 0.05$.

3.5. Watering Demands

According to contemporary water management standards, retention should support the irrigation of growing plants (Moser et al., 2017). The water demands of plants depend on many factors: plant size, season (including temperature, leaf size), plant species, and climatic or local conditions. Irrigation requirements can be calculated based on the evapotranspiration index, using the principle that evaporated water should be replaced through irrigation. The most popular models are the four models of the ETo index: a model based solely on temperature measurements; Garbarczyk's model based on air temperature and humidity measurements; the Hargreaves model, calculated based on temperature and latitude; and the Penaman–Monteith model, calculated based on temperature, altitude, air humidity, radiation, and wind speed. All these models were developed for production plants, including fruit trees. The frequency of watering is also important. The best growth conditions are achieved by water-spraying trees, which means less frequent (once a week or less) but more abundant watering. Bartosiewicz (1986) recommends periods of 20–40 days between watering trees and giving a single dose of 50–100 l/m^2 under the canopy of trees, assuming a depth of 30–60 cm. On the other hand, Borowski et al. (2016) do not distinguish between the amount of water required for watering trees. They only discuss watering a layer of 35 cm of soil for deeper-rooting plants and give the value of 35 l of water per m^2 of the area under the tree canopy or the vegetated surface for other plants. For trees, we can also calculate the amount of water using the breast height diameter (DBH). This method assumes a conversion factor whereby one centimetre of trunk diameter equals 10 l of water per every 20–40 days (Bartosiewicz, 1986).

3.6. Insolation Analyses

Insolation analyses should begin at the concept stage of design proposals (Saratsis et al., 2017). Sunlight studies in the urban context focus mainly on proper daylight illumination of rooms. Good insolation is vital for the energy efficiency of a facility, the possibility of supporting natural ventilation, or obtaining solar energy (Hegger et al., 2008). The arrangement of a building can have an effect on indoor insolation (Fernandez et al., 2015). Outdoor conditions have so far received less attention. The outdoor environment can contribute to providing sufficient ventilation and preventing heat island. Insolation should be considered when deciding the location of renewable energy sources. It is also essential for public space design, in terms both of its social aspects and green and blue infrastructure requirements. In the following section, we focus on the impact of insolation on vegetation growth conditions.

4. Case Studies

The need to adapt to climate change is now widely recognised among scientists, politicians, and municipal decision-makers (e.g., City of Paris, 2018; European Commission, 2021; European Environment Agency, 2016; Kassenberg et al., 2019; Mayor of London, 2018; Reusswig et al., 2016). However, in many cities, including Polish ones, the implementation of measures aimed at tackling climate change has not started or is not advanced. Urban adaptation plans have been elaborated for 44 major Polish cities, but the transformation of the urban fabric, taking into account the consequences of climate change, has not gained momentum. We attribute this situation to the lack of well-established methods for adapting the built environment to new conditions, despite many studies that provide adaptation guidelines (e.g., Crichton et al., 2009; Filho, 2015; Jones, 2017; Košir, 2019; Naumann et al., 2020). First, every local situation is different. Cities differ in their latitude and climatic conditions (Stewart & Oke, 2012), which has consequences for the choice of adaptation measures. Moreover, for each site, adaptation strategies must respond to the local conditions and, above all, cater to the demands of the local community. At the same time, they should harmoniously fit into the surrounding urban fabric and the local system of ecological connections. Adaptive transformations relate to several design levels, from the regional and city level (spatial and urban planning) to the neighbourhood scale (urban design), and from spatially separated parts of districts (housing estates, urban blocks) to the scale of a single building.

To verify the assumed methodology and formulate adaptation recommendations, we selected two sites: Grzybowski Square, in Warsaw, and the Old Market, in Lodz. We analyse these two public spaces against the backdrop of surrounding neighbourhoods. We pay special attention to the relations between the urban vegetation and the adjacent system of urban greenery. Both sites are centrally located and both used to work as urban nodes in the past. Moreover, both contain a certain amount of vegetation and are connected to neighbouring GI (Figure 1). Both Warsaw and Lodz have strategic documents defining the directions of adaptation (City of Lodz, 2018; Kassenberg et al., 2019). However, they are awaiting more specific guidelines.

4.1. Grzybowski Square, Warsaw

Grzybowski Square was the market square of Grzybów "jurydyka," established in 1650 and incorporated into the capital at the end of the 18th century. It owes its triangular shape to its location at the intersection of transportation routes. Initially surrounded by one- or two-storey wooden buildings, from 1820 its facades were gradually replaced with five-floor masonry tenement houses.

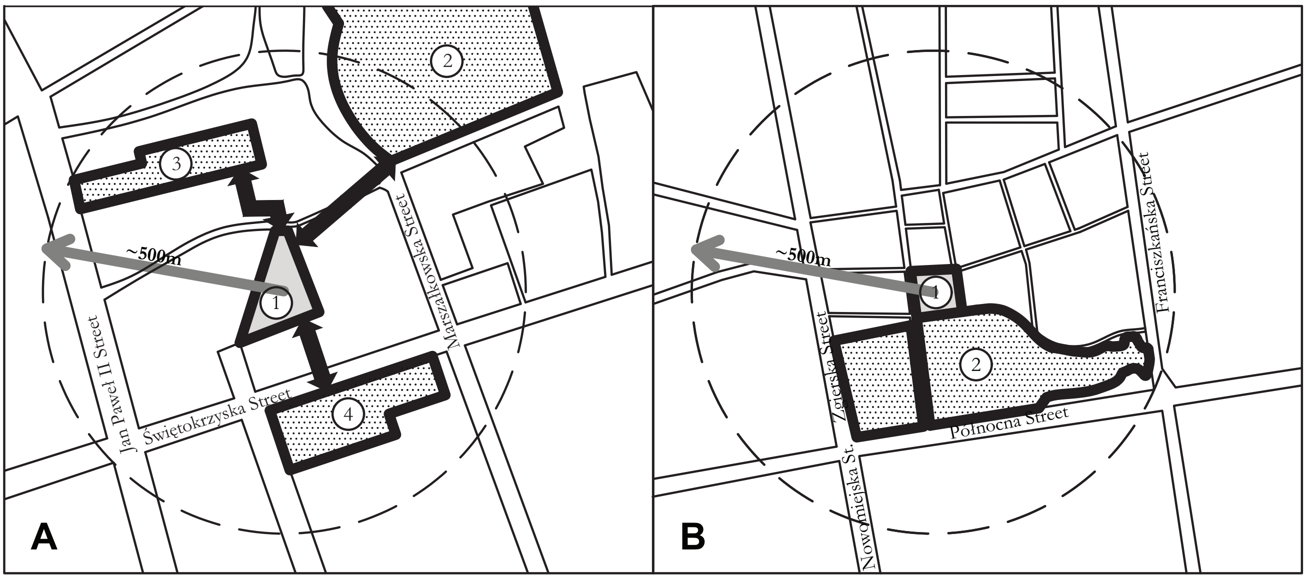

Figure 1. A) Location of city parks in the vicinity of Grzybowski Square (within 0.5 km): 1. Grzybowski Square, 2. Ogród Saski (The Saxon Garden), 3. Park Mirowski (Mirowski Park), 4. Park Świętokrzyski (Świętokrzyski Park); B) Location of city parks in the vicinity of Old Market Square (within 0.5 km): 1. Old Market Square, 2. Park Staromiejski (Staromiejski Park).

The prominent landmark, All Saints' Church, was erected between 1861 and 1879. During the Second World War, the square became part of the Jewish ghetto. Only a few buildings from before 1939 have survived; others were destroyed during wartime or later replaced with housing estates. The post-war residential towers were higher (13 floors) and did not strictly follow the historical layout (Figure 2A). The current development of the square (Figure 2B) also includes office and service buildings since 1989, including the Cosmopolitan skyscraper (2014). A new high-rise to replace the Jewish Theatre demolished in 2017 could reach the height of the nearby skyscraper, according to visualisations made available by the investor.

From the mid-17th to almost the end of the 19th century, the square was a place of trade. Until 1820 it was unpaved. In 1897, with the completion of the main church construction works, it was decided to remove the market. The square was partially de-paved, and a fenced green area was created. Trees were planted both on the green space and along the frontage. After the war, the square and the entire area was neglected for many years. In 1969, the modernisation of the interior of the square began.

As a result, paths cutting across the pre-war green area were created, and the avenue which was to lead on its extensions to the Saski Garden and Świętokrzyski Park was emphasised with tree rows (Figure 2A). In this way, it was planned to link the greenery of the square with the broader system of urban greenery. In 2007, the artist Joanna Rajkowska created an installation—the oxygenator—in the square. This inspired a competition to modernise the square. The new solution limited and arranged parking, reorganised the traffic rules, and rearranged the greenery of the square and its other elements (Figure 2B). The green area decreased. Table 4

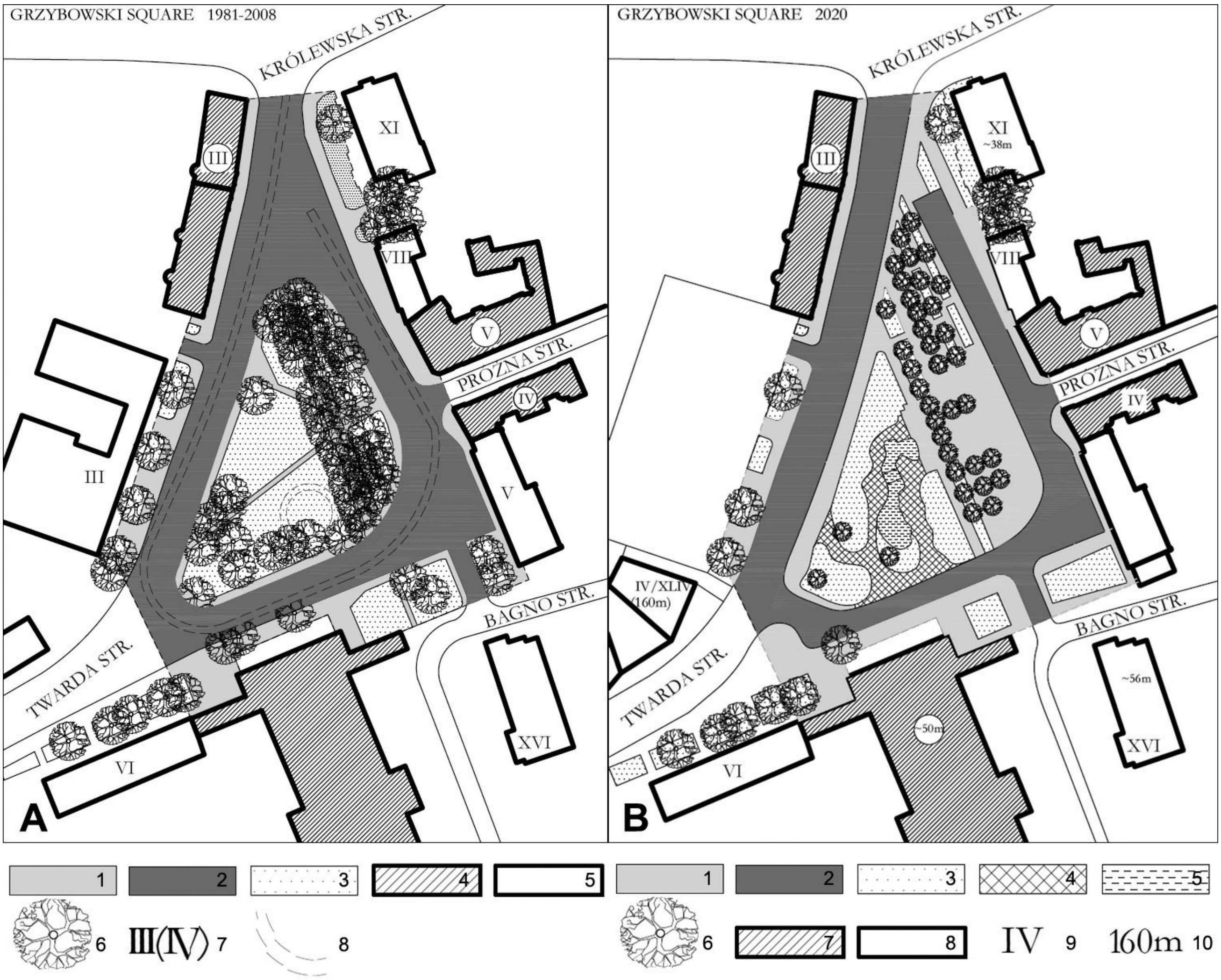

Figure 2. Grzybowski Square. A) 1981–2008. Legend: 1. Pavement/concrete slabs, 2. Roadways and parking (tarmac), 3. Lawns, 4. Pre-war buildings, 5. Buildings since 1945, 6. Trees, 7. Number of floors (overbuilt), 8. Oxygenerator 2007, and 9. Unused tramway tracks; B) 2020. Legend: 1. Pavement, 2. Roadways and parking (tarmac), 3. Lawns, 4. Permeable surface, 5. Water surface, 6. Trees, 7. Pre-war buildings, 8. Buildings since 1945, 9. Number of floors, and 10. Maximum building height.

Table 4. Grzybowski Square, Warsaw: Percentage share of different surfaces in the area of the square.

		End of the 19th Century	1900–1939	1981–2008	2020
Paved area:	Pedestrians	100% (15,000 m²)	25% (3,800 m²)	27% (4,250 m²)	40% (6,300 m²)
Impervious surface	Traffic		36% (5,400 m²)	43% (6,600 m²)	33% (5,100 m²)
Permeable surfaces					5% (800 m²)
Biologically active surface			39% (5,800 m²)	30% (4,750 m²)	20% (3,100 m²)
Water surface					2% (300 m²)

Notes: Permeable surface, other than biologically active surface, including "threshing floor." All values included in the table are approximate.

presents the share of different surfaces in the total surface of the square. These values were used in the further calculations.

4.2. The Old Market, Lodz

The Old Market dates back to when Lodz received city status in 1423. The low wooden structures which surrounded the square were gradually replaced by masonry buildings (up to three floors high) in the 19th century. The buildings surrounding the square became dilapidated during the Second World War, when this site was included in the Jewish ghetto. In the post-war period the structures were replaced by housing estates and a newly created park from the south (Figure 3). The site lost its former role as a node of local life.

Until the middle of the 19th century, the surface of the square was entirely unpaved. In 1841, paving of the road began, followed by two lanes of pavement crossing the square's surface, which ensured more efficient transport of goods to the stalls. In 1925, it was decided to transform the square into a town square. Trees and lawns appeared. After the war, the greenery in the central part was replaced by lawns with rows of trees along the frontage. The central part of the square was paved over. Currently, the municipality plans to modernise the

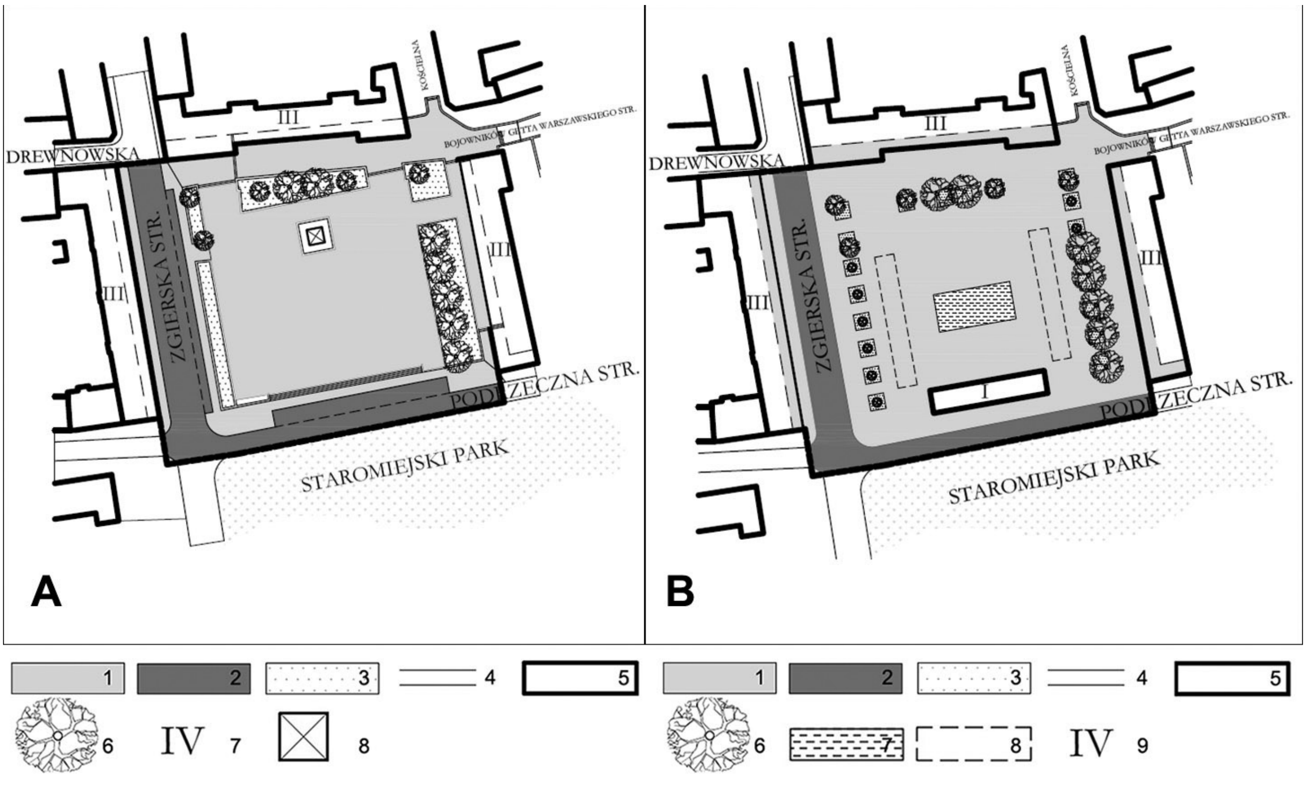

Figure 3. Old Market Square, Lodz. A) 1956–2021. Legend: 1. Pavement, 2. Roadways, 3. Lawns, 4. Trees, 5. Buildings, 6. Tramway tracks, 7. Number of floors, 8. Monument of Julian Marchlewski (1964–1989); B) Concept design of 2016 planned redevelopment, designed by Jakub Krzysztofik, Sylwia Krzysztofik, and Michał Domińczak. Legend: 1. Pavement, 2. Roadways, 3. Lawns, 4. Trees, 5. Buildings and new pavilion, 6. Tramway tracks, 7. Number of floors, 8. Light structures (canopies, design stalls), 9. Pavement fountain.

square together with the neighbouring park. Trees are to remain on the square; the biologically active surface is to be reduced; and the pavement is to be replaced and complemented with new street furniture and a small pavilion on the park side. Table 5 presents the share of different surfaces in the total surface of the square. These values were used in further calculations.

5. Results

In the analysis, we focused on three connected aspects of the urban environment: surface runoff; the watering demands of trees; and the insolation of urban spaces.

5.1. Calculation of Surface Runoff and Watering Demands

For Grzybowski Square in Warsaw, surface runoff was calculated according to the above formulae where:

$A_1 = 6,300\ m^2 + 5,100\ m^2 = 11,400\ m^2$;

$A_2 = 800\ m^2; A_3 = 3,100\ m^2$

$\Psi_1 \times A_1 = 0.90 \times 11,400\ m^2 = 10,260 m^2$

$\Psi_2 \times A_2 = 0.15 \times 800\ m^2 = 120\ m^2$

$\Psi_3 \times A_3 = 0.05 \times 3,100\ m^2 = 155\ m^2$

$\Sigma A = 11,400\ m^2 + 800\ m^2 + 3,100\ m^2 = 15,300\ m^2 = 1.53\ ha$

$\Psi_m = (10,260\ m^2 + 120\ m^2 + 155\ m^2)/11,300 = 0.93$

$Q_r = 177.1\ l/s \times 0.93 \times 1.53\ ha \approx 252\ l/s$

$252\ l/s \times 15\ min (900\ s) = 226,800\ l = 226.8\ m^3$ of water

Therefore, the surface runoff for Grzybowski Square amounts to 226.8 m^3 = 226,800 l.

The NDVI map for Grzybowski Square in Warsaw (Figure 4) shows the intensity of the photosynthesis process. As can be clearly seen, the white chestnut trees (*Aesculus hippocastanum*) on the west side in zone A have a reduced NDVI, and the row of Crimean limes (*Tilia x euchlora*) in zone B are weakened. The analysis shows the negative effect of the difficult urban conditions on the stand, including the reduction in the water-permeable surface under the trees implemented as part of the competition project in 2008. As a result, the Crimean lindens suffer from periods of urban drought. The irrigation needs of the 16 Crimean lindens on Grzybowski Square in zone B with an area under the canopy of approximately 350 m^2 and a total DBH of around 465 cm are as follows:

- 17,500 l of water for a single watering, assuming 50 l/m^2 (Bartosiewicz, 1986);
- 4,650 l of water for a single watering, assuming a calculation based on DBH (Bartosiewicz, 1986);
- 12,250 l of water for a single watering of a Crimean lime, according to the index from the Standards (Borowski et al., 2016);
- Assuming a watering model based only on the temperature, the demand of 16 Crimean limes on a day with an average temperature of 21°C will be 3.5 mm, which gives circa 12,250 l of water necessary for watering. This calculation was made using the online abacus on the website of the Platform for Supporting Irrigation Decisions (https://geoportal360.pl/map/#l:52.23589,21.0037,19;p:MTQ2NTEwXzguMDMwNi40Ny80).

As can be seen, different methods can produce varying results. The lowest water demand index is generated by estimates based on DBH. Calculations based on the temperature model and the Standards (Borowski et al., 2016) are identical and resemble estimates by Bartosiewicz (1986).

Based on the data obtained from calculations based on the Standards (Borowski et al., 2016) and the 12,250-l temperature model, the retention capacity of Grzybowski Square can cover 18 waterings per season. Proportionally, all 46 trees (assuming needs of 35 l/m^2) require an average of 35,220 l, which would be satisfied by six waterings from retention water. Considering the need for watering on average once a month (Bartosiewicz, 1986), we can assume that the retained water would ensure the needs of the trees throughout the growing season (in the spring and autumn months rainfall reduces watering needs).

The calculation of water demands from trees in the Old Market, Lodz, is given in Table 6.

The retention capacity in the design proposal for the Old Market Square, assuming generalised data, would

Table 5. Old Market Square, Lodz: Percentage share of different surfaces in the area of the square.

		1917	1925–1939	1956–2020	Concept Design
Paved area:	Pedestrians	10% (900 m^2)	40% (3,600 m^2)	66% (5,900 m^2)	78% (7,000 m^2)
Impervious surface	Traffic	40% (3,800 m^2)	28% (2,700 m^2)	22% (2,000 m^2)	17% (1,500 m^2)
Permeable surfaces		50% (4,600 m^2)			
Biologically active surface			32% (3,000 m^2)	12% (1,100 m^2)	5% (500 m^2)
Water surface					Pavement fountain

Notes: Permeable surface, other than biologically active surface, including “threshing floor.” All values included in the table are approximate.

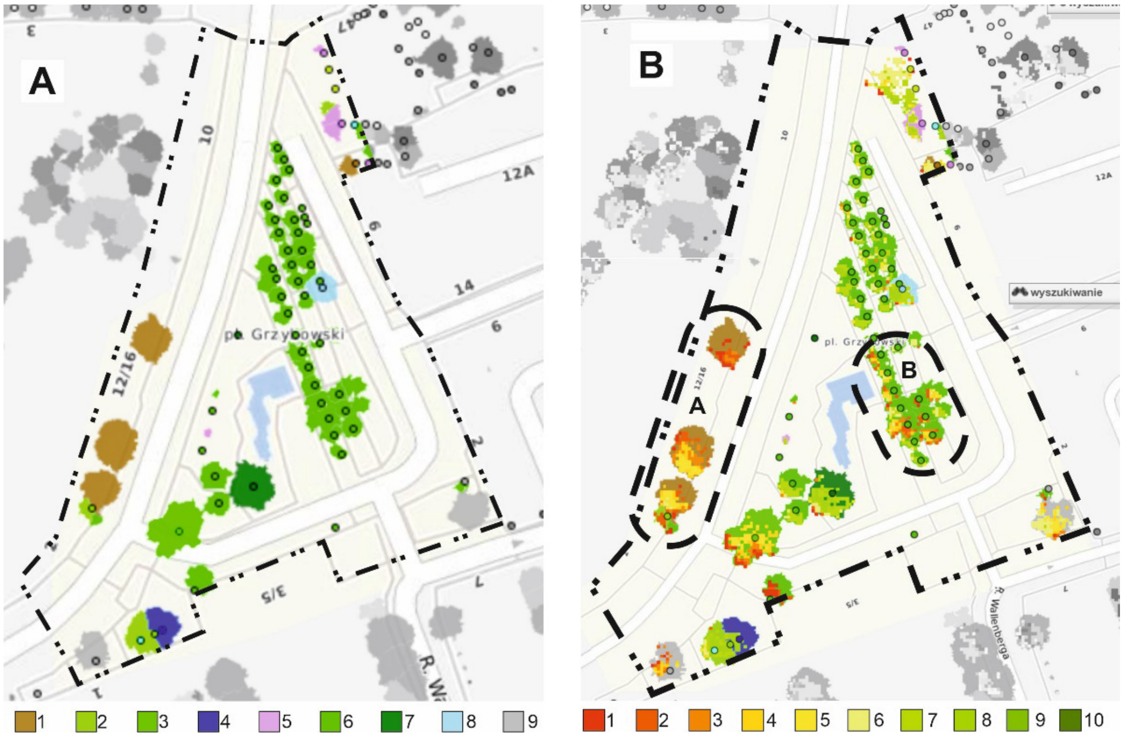

Figure 4. A) Map of tree species and crown cover. Legend: 1. Aesculus sp., 2. Acer sp., 3. Populus sp., 4. Robinia sp., 5. Prunis sp., Malus sp., and Pyrus sp., 6. Tilia sp., 7. Quercus sp., 8. Ulmus sp., 9. Others; B) Map of NDVI for Grzybowski Square in Warsaw. Legend: 1. 0.00–0.50, 2. 0.50–0.60, 3. 0.60–0.65, 4. 0.65–0.70, 5. 0.70–0.75, 6, 0.75–0.80, 7. 0.80–0.85, 8. 0.85–0.90, 9. 0.90–0.95; 10. 0.95–1.00. Source: Biuro Geodezji i Katastru (n.d.).

supply six to eight waterings of the trees in the square. In the current state, the surface runoff is smaller and more water is retained. As in the case of Grzybowski Square, the retained water in the Old Market Square can cover watering of trees throughout the growing season. This refers both to the current state and the design proposal. However, the higher share of previous surfaces might enable better conditions for the growth of local vegetation, including trees.

5.2. Insolation Analyses

Insolation analyses enabled us to determine the conditions resulting from the shape and dimensions of the urban fabric. The results can inform recommendations for public space design, including GI, minimising the UHI, using solar energy, etc. Model studies were carried out on virtual 3D models of Grzybowski Square in Warsaw and Old Market Square in Lodz and the surrounding areas

Table 6. Old Market Square, Lodz: Calculations of water demand from trees in the current state and in the design proposal.

Watering Demand From Trees		
Method	Current State	Design Proposal
50 l/m^2 (Bartosiewicz, 1986)	12,000 l	20,000 l
Calculations based on DBH (Bartosiewicz, 1986)	3,480 l	5,800 l
Index based on the Standards (Dworniczak & Reda, 2019) *	12,000 l	20,000 l
Watering model based on temperature, the demand on a day with an average temperature of 21°C will be 3.5 mm **	8,400 l	14,000 l
Surface runoff	116,000 l	122,000 l

Notes: In the current state there are 12 trees with a crown area of 240 m^2 and a total DBH of 348 cm. In the design proposal there are 20 trees (12 existing and eight newly planted). The crown area has been estimated as 400 m^2 and DBH as 580 cm. The watering demands refer to one-time spray irrigation. * The indicator from "Standards for shaping greenery in Lodz (project)" (Dworniczak & Reda, 2019) states that 50 cm of soil should be irrigated, i.e., the converter value equals 50 l/m^2. ** Assuming a watering model based solely on temperature, the demand of trees on a day with an average temperature of 21°C will be 3.5 mm (35 l/m^2). The calculations were made using the online abacus on the Platform for Supporting Irrigation Decisions (https://geoportal360.pl/map/#l:52.23589,21.0037,19;p:MTQ2NTEwXzguMDMwNi40Ny80).

using Archicad software, on dates significant from the point of view of vegetation growth (Figure 5). The insolation was analysed on the days of the equinoxes (March 20 and September 22) and on the longest day of the year (June 21), as these dates show the boundary conditions and significant parameters of insolation.

The analysed area in the Old Market Square in Lodz is well lit by daylight. Its area is dominated by a zone of two to three hours of shade. This creates favourable conditions for the development of vegetation in the square. Significant sunlight raises the risk of an UHI, if fast-heating or dark materials are used. Shaded zones for up to four hours are located on the eastern and western frontages of the square. Significantly shaded zones were not observed.

Most of the Grzybowski Square area is suitable for photophilous plants. In a large area, it is also possible to obtain energy from solar sources. In the designated area, which is also sunny in the autumn and spring, photocatalytic materials can be used to minimise air pollution (smog) in the autumn and winter periods and early spring. The southern frontage of the square is a suitable place for shade plants. The remaining part of the square is suitable from the point of view of insolation for the development of urban vegetation.

6. Discussion and Recommendations

In our investigation, we calculated surface runoff, the watering demands of trees, and insolation in urban spaces. The surface runoff combined with the watering needs of urban vegetation makes it possible to define a balanced state when the vegetation requirements are satisfied. Similarly, our study of insolation enables identification of the proper conditions for trees and other species to thrive in urban areas. These features contribute a limited piece to a holistic image of the complex nature of urban ecosystems, which can be used to ensure the resilience of urban greening interventions. In particular, the features relate to "nature type 3"—functional greening, using the typology introduced by Kowarik (2005). Other elements that should be considered include the temperature regulation, the urban water cycle, air flow regulation, and creating proper outdoor conditions for social activities.

Our survey of the existing methodologies shows that the results of modelling depend strongly on local conditions, in terms of local climate, native species, and the features of the physical environment. The species and local biodiversity further depend on climate change and management processes. For instance, while fertilisers support plant growth and CO_2 sequestration, they do not contribute to plant biodiversity (Köhler & Kaiser, 2021). Under the changing climate conditions in Central European cities, drought-tolerant plants are required. Plants need to be adjusted to future climatic conditions. Köhler and Kaiser (2021) and Liu et al. (2019) recommend prairie plants from North America for Central Europe under drought conditions. Another recommendation is to permit weeds that can withstand extreme drought conditions (Vanstockem et al., 2019) to increase biodiversity and resilience. Capturing morning dew, which works better on horizontal surfaces (pavements, green roofs), can also help ensure water resilience (Heusinger & Weber, 2015; Köhler & Kaiser, 2021). Due to the high complexity of the involved phenomena and their interdependencies and local specificity, these topics require further exploration.

The specific parameters of each element in the system depend on the others. For example, trees are more efficient at sequestrating CO_2 when they feature higher leaf area index and NDVI values. These parameters, in turn, depend on the conditions of the trees, which depend on proper watering and insolation.

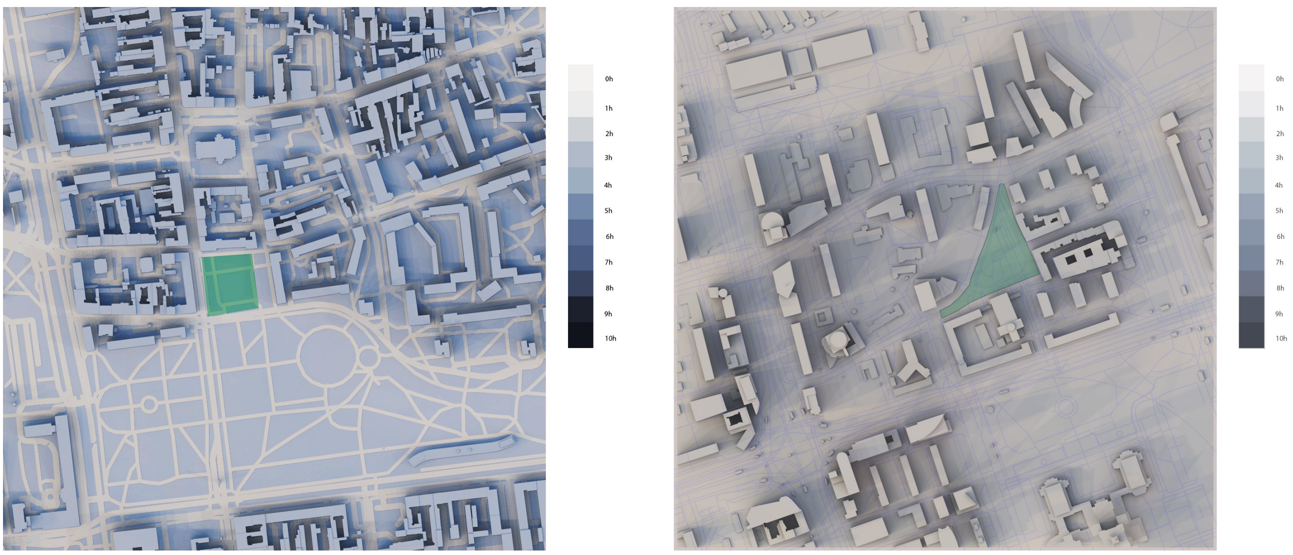

Figure 5. Analyses of the shading of the area and surroundings of Old Market Square in Lodz (left) and Grzybowski Square in Warsaw (right) on March 20, June 21, and September 22. The legend shows the number of hours of shade.

Our study shows that these requirements might be satisfied by verifying the water and insolation conditions at the design stage. In both squares, we recommend increasing the amount of greenery, including large trees and elements of blue infrastructure, to improve the hygrothermal conditions. Due to the likelihood of high transpiration, we suggest using water-permeable paving materials. To improve the conditions for urban vegetation we recommend limiting the height of buildings surrounding the squares to assure proper insolation and strengthening the connections with the surrounding green areas.

7. Conclusions and Future Research Pathways

In this article, our goal was to define a normative framework for urban design integrating urban greenery. The collected parameters related the features of urban vegetation to the physical city fabric. We used regulatory ecosystem services as a reference to evaluate the impact of animate and inanimate elements of the urban environment. We discussed in detail the methodology for assessing some of the parameters for describing those elements. Furthermore, we proposed an assessment of two public spaces, with a focus on the functioning of urban vegetation versus the surrounding environment. The evaluation was based on the balancing of water retention and water demand from trees. It was completed by an analysis of insolation to determine the conditions for urban vegetation growth. Even the limited number of features considered provides some preliminary insights into the complexity of the functioning of the urban ecosystem. Future work should consider other aspects of the urban environment from the social-ecological systems perspective. Additional extensive research is needed to further grasp the complexity of combined green, blue, and grey infrastructure in cities.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

Bioconnections as Enablers of Regenerative Circularity for the Built Environment

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Abstract
Learning from nature may be the most important step towards improving cities in the context of environmental and climate issues. However, many of the current approaches to make cities greener or more sustainable are still linear and insufficient to deal with these growing challenges. In this scenario, the adoption of regenerative and circular lenses for the built environment may foster a more holistic development based on what is good rather than what is less bad. In this article, we propose that bioconnectivity or bioconnections—a nature-focused approach based on biophilic design, biomimetics, and ecosystem services—may be an important enabler for the regeneration of the ecological and social boundaries of the planetary boundaries and doughnut economics models. We examine the literature to identify in what ways bioconnections could facilitate circular and regenerative processes for the local scale of the built environment domain. We complement the discussion with some real-world examples from selected urban communities or interventions in existing urban areas around the globe that claim a green approach. In the end, we propose a framework of relevant bioconnections for the built environment that could facilitate addressing ecological and social boundaries at the local urban scale and facilitate processes of regenerative transitions towards thriving communities.

Keywords
circular economy; circularity; nature-based solutions; regenerative design and development; urban bioeconomy; urban green infrastructure; urban sustainability

Issue
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1. Introduction

Humanity faces a diverse set of global challenges. The consequences of unfettered development have been the overshooting of key planetary ecological boundaries (Rockström et al., 2009). The global annual extraction of resources has increased from 27 billion tons to 92 billion tons in 47 years (IRP, 2019), with only 8.6% of the resources cycling back into the economy (Circle Economy, 2021), and 50% of the use happening because of cities (IRP, 2018). In response, an increasing number of buildings and communities have claimed to be green, ecological, or sustainable—many still based on a fragmented and linear approach.

Therefore, we need disruptive changes to reverse the trend and start directing systems towards a regenerative and circular economy and society.

“Regenerative design,” proposed by John Lyle, has strong roots in metabolic and “systems thinking” of self-renewing flows and stocks, to “replace the present linear system of throughput flows with cyclical flows” (Lyle, 1994, p. 10), which evolved into a more holistic approach with a vision of humankind integrated and co-evolving with nature to achieve positive impact (Reed, 2007).

The idea of circular systems, which Birkeland (2019) categorises into hard/technocratic, soft/social, and living/organic systems, had been proposed a few decades earlier in the wake of the space race through the idea of Earth as a spaceship (Fuller, 1969), an enclosed cyclical ecological system (Boulding, 1966/2011). This later developed into circular economy through the works of many authors as Stahel (1982), Pearce and Turner (1989), and, more recently, the Ellen Macarthur Foundation (2013). There is, however, strong criticism that circular economy's technocratic emphasis does little to reduce the capitalist and materialistic approach to resources and reduced focus on social aspects (Calisto Friant et al., 2020).

One way of addressing this issue is the "doughnut economics" (DE) model (Raworth, 2017). The doughnut is composed of two concentric circles that represent the ecological and social boundaries, i.e., the limits of different global systems we must not overshoot to maintain humanity's wellbeing. The inner circle represents the social boundaries or social foundation, as access to food, health, education, social equity, among others, below which society would be falling short of their life's essentials. The outer circle, or the ecological ceiling, incorporates the "planetary boundaries" (PB) framework, which defines the safe operating space within which Earth's biophysical systems and processes (e.g., climate change, freshwater, biodiversity, among others) should operate (Rockström et al., 2009; Steffen et al., 2015). Although not specifically designed to be downscaled to the local scale, applying PB thinking at the local level is desirable (Steffen et al., 2015). As such, both PB (Figure 1a) and DE (Figure 1b) have been represented at the national (Lucas & Wilting, 2018; O'Neill et al., 2018) and city (Hoornweg et al., 2016; Norman & Steffen, 2018) levels. Desing et al. (2020) proposed circular economy as a pathway for companies to improve resource use based on PB limitations, and Amsterdam was the first city to include DE into its guide for a circular and regenerative city (DEAL et al., 2020).

As we approach the sixth major extinction event with increasing loss of biodiversity, including biodiversity impacts of climate change (Chapin et al., 2000) and resource use (IRP, 2019), it is of particular importance to understand how the built environment of cities can contribute to regenerating ecosystems. Circular economy studies usually emphasize the benefits of technical solutions and ignore how potential increases in production under a consumerist mindset could lead to more impacts on the biosphere (Buchmann-Duck & Beazley, 2020). A nature-based focus, however, can be an important enabler of ecological and social boundaries.

Thus, as circular economy is increasingly advocated by governments (European Commission, 2019, 2020) and businesses (Ellen MacArthur Foundation, 2020), circular practices should evolve from their focus on resources to positively contribute to the biosphere and society through a more systemic approach, a "regenerative circularity" to reverse the impacts from the flows of resources into cities without ignoring social aspects. The incorporation of "nature-based solutions"—the "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (International Union for Conservation of Nature, 2016)—into regenerative and circular design for the built environment has been increasingly explored. Pedersen Zari looked into "ecosystem services"—the benefits

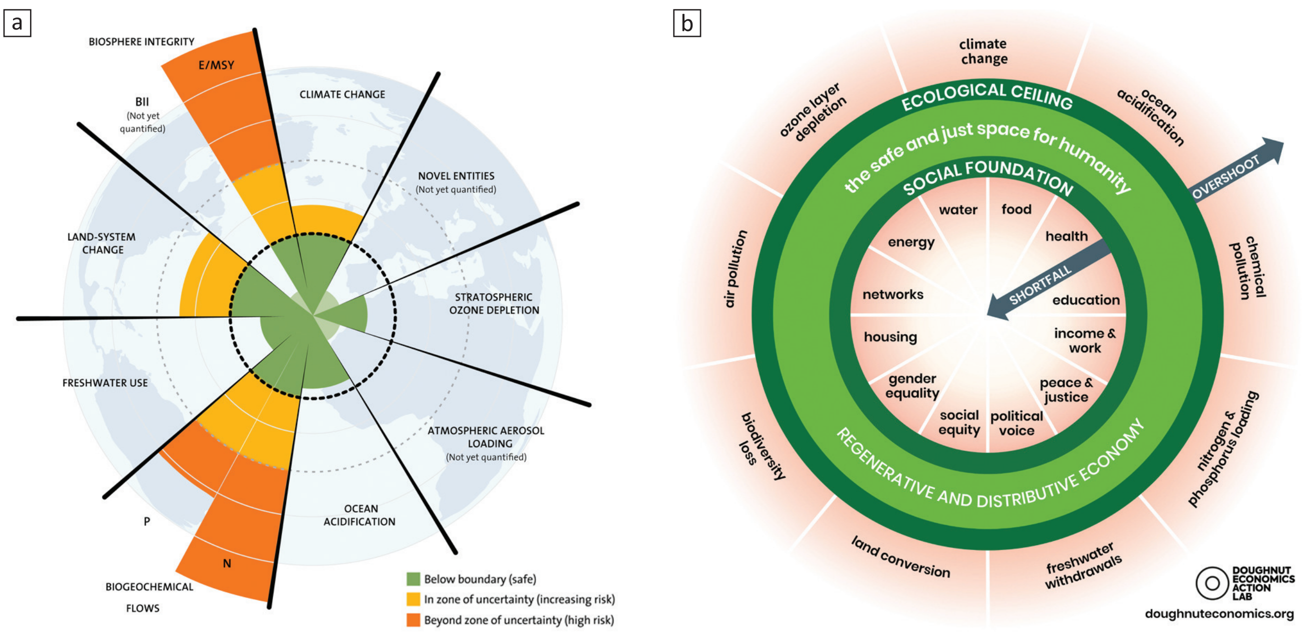

Figure 1. (a) PB framework, and (b) the "doughnut" of social and PB. Sources: (a) J. Lokrantz/Azote, based on Steffen et al. (2015); (b) Kate Raworth and Christian Guthier (CC-BY-SA 4.0; Raworth, 2017).

from nature to humankind (Millennium Ecosystem Assessment, 2005)—for regenerative urban design (Pedersen Zari, 2015) leaving cultural ecosystem services aside and examined energy and water provision (Pedersen Zari, 2017a) and materials selection (Pedersen Zari, 2017b), but without direct linkages to PB or DE.

Building on those precedents, this article proposes adopting a "nature" perspective (Figure 2), which here we call "bioconnectivity" or "bioconnections," to improve circular and regenerative practices in the built environment as a way of addressing the ecological and social boundaries of the DE model. First, we look into different concepts to define the idea of bioconnections, then, for selected ecological and social boundaries, we examine the literature to map in what ways bioconnections could facilitate circular and regenerative processes for the local scale. We complement the discussion with some examples from selected urban communities or interventions in existing urban areas around the globe that claim a green approach. Finally, we propose a framework of relevant bioconnections for each ecological and social boundary.

2. Bioconnections for a Regenerative and Circular Built Environment

There are different ways in which bioconnectivity or bioconnections—i.e., the solutions, initiatives, interventions, or strategies that promote the reconnection between humans and nature, ensuring adequate stewardship, maintenance, and regeneration of biodiversity, enabling the provision of ecosystem services sustainably into the future—could be encouraged in urban environments. Benyus (2015) suggests the cities of the future should be *generous*, i.e., inspired by how a forest works and function as giant organisms, which treat their water, sequester carbon, clean the air, produce food and energy, among other functions. This reflects her previous work on "biomimicry," the development of technical solutions based on natural mechanisms (Vincent et al., 2006). More than inspiring solutions, bioconnections encompass the ideas of "biophilia," "the innately emotional affiliation of human beings to other living organisms" (Kellert & Wilson, 1993, Chapter 1, para. 1), nature-based solutions, and ecosystem services. These different approaches, when in tandem, may support the evolutionary transition from degenerative to regenerative proposed by Mang and Reed (2012).

Bioconnected solutions are progressively becoming reality in urban planning and architecture through "green infrastructure" interventions. Green infrastructure refers to "the network of natural and semi-natural areas… which together enhance ecosystem health and resilience, contribute to biodiversity and benefit human populations through the maintenance and enhancement of ecosystem services" (Naumann et al., 2011, p. 14). Working with bioconnectivity in cities requires acknowledging the unique features of urban biodiversity that derive from anthropogenic alterations (Ellis & Ramankutty, 2008), and the need for novel adaptive ecosystems for a changing climate (Oke et al., 2021), which may not allow restoring urban areas to their previous condition (Murphy, 2015).

In the following sections we seek to identify and explore in what ways bioconnections may enable a regenerative and circular approach to ecological and social boundaries in the built environment. We reinterpret selected ecological and social boundaries for a built environment context and consider their links with ecosystem services (Pedersen Zari, 2012).

2.1. Climate Change

Biobased climate change mitigation is an important ecosystem service. Apart from local greenhouse gas emissions from fossil-fuel energy and waste (Norman & Steffen, 2018), cities rely heavily on high-emitting industries outside their borders, such as agriculture and forestry, resource extraction, and energy generation (Hoornweg et al., 2011).

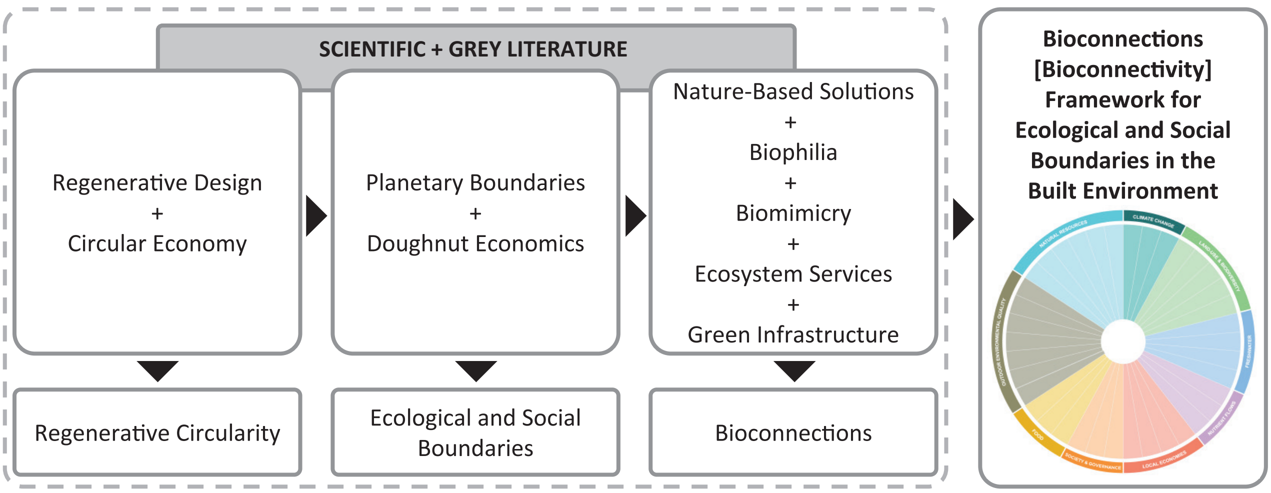

Figure 2. Methodological flowchart.

Carbon sequestration and storage through photosynthesis, biomass, and soil media are the most straightforward solutions through urban forests (Nowak & Crane, 2002) and other types of green infrastructure in general (Chen, 2015). In green roofs, plant selection and soil characteristics are key drivers of carbon sequestration (Luo et al., 2015). Indirect contributions may arise from the impact of vegetation on buildings' energy demand for thermal comfort (Shafique et al., 2020).

Algae is a promising resource for energy generation. Microalgae photobioreactors are more efficient than other types of biomass; they also extract nutrients from wastewater, produce oil, and biomass that may be used as biofuel, fertiliser, animal feed, or generate biogas to produce electricity (Elrayies, 2018). In Hamburg's Wilhelmsburg eco-district, the Bio-Intelligent Quotient house (Figure 3) is the first bio-reactive panel façade using microalgae and solar thermal energy to generate electricity and heat (IBA Hamburg, 2013), a technology that could be expanded to urban scale applications.

Carbon storage in biobased construction materials by using engineered wood and bamboo from sustainable reforested sources could create carbon pools in cities (Churkina et al., 2020). Comparatively, bamboo products may remove five to six times more carbon from the atmosphere than timber (Hinkle et al., 2019). Long-term management of stored carbon requires life cycle thinking in which buildings are designed for adaptation through modularity, durability, flexibility, and reversibility (Zimmann et al., 2016), thus achieving circularity in construction. It also entails giving new uses for removed urban trees that would otherwise be mulched or burned (Nowak & Crane, 2002). The treatment of organic waste through composting under adequate conditions is key to reduce the associated greenhouse gases emissions (Zhu-Barker et al., 2017).

2.2. Land-Use and Biodiversity

Land-use change and biodiversity loss are strongly connected, e.g., through the conversion of biodiverse areas into farmlands (Norman & Steffen, 2018). If we are to feed people, we need regenerative farming and permaculture practices in rural areas (Rhodes, 2017).

In cities, the long lifespan of buildings and infrastructure may dictate how they operate for centuries (Floater et al., 2014). Hence, containing urban sprawl with green belts, while finding the right balance between high-quality densification and green spaces, using multifunctional spaces, or even finding voids to add greenery, are challenges to be solved (Haaland & van den Bosch, 2015). Add to the list preserving and regenerating remnant natural areas and greening every space, from private to public areas, from horizontal to vertical surfaces, either permanently or temporarily (Parris et al., 2018), connecting green patches, and creating conditions for natural processes as pollination, succession, and habitat provision, to thrive (Garrard et al., 2017). The Covid-19 pandemic may present new opportunities to rethink the use of city buildings and public spaces.

In the Bo01 precinct (Figure 4), in Malmö's Västra Hamnen area, Sweden, biodiversity in design was led by two planning instruments, "green space factor" and "green points system," developed for promoting biodiversity, managing stormwater, and creating a healthy neighbourhood (Kruuse, 2011). While the first instrument seeks to increase plots vegetated and permeable areas by achieving a minimum score based on different types of surfaces weighted by their area, the latter increases ecological value by selecting strategies from a pre-determined list to enhance and regenerate local biodiversity and natural cycles. The final design offers multifunctional and liveable urban spaces in contact with nature.

Building facades and lighting have an impact on wildlife, as bird collisions, which could be mitigated by reducing the exposed area of glass and emitted light in facades and adding external elements or printed patterns in glass (Sheppard & Phillips, 2015). Light pollution also impacts human health and disrupts fauna and flora, demanding attention to the design of façades and outdoor lighting systems (Chepesiuk, 2009).

Pollination is a vital ecosystem service, but its contributions to food security and ecosystem health, mostly by bees, are under threat due to climate change, pesticides, and other causes (Potts et al., 2016). Bees, however, seem to better function in the dynamic of urban environments with reduced use of pesticides, exposed

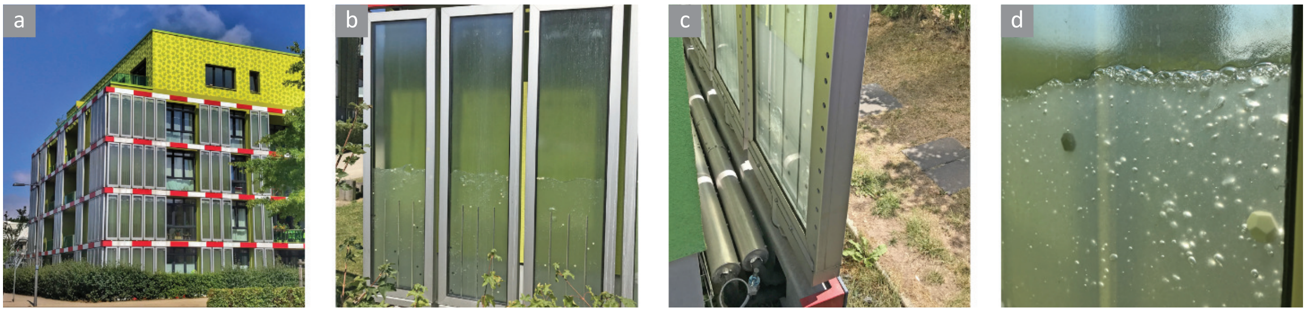

Figure 3. Bio-Intelligent Quotient house in Wilhelmsburg, Hamburg: (a) facades; (b) photobioreactor panels; (c) and (d) details of the photobioreactors.

Figure 4. Bo01 precinct in Malmö: (a) Bo01 courtyard with water body; (b) and (c) Bo01 streetscape-integrated elements for stormwater management; (d) and (e) Bo01 water bodies as a part of the urbanscape; (f) and (g) Bo01 courtyard gardens; (h) Bo01 green roof on a residential building.

land, dead wood, cavities in buildings, and continuity of floral resources (Theodorou et al., 2020). In Oslo's Vulkan green precinct, a former industrial area, the importance of bees and pollination led to a beehive at the top of a building (Figure 5), taking advantage of surrounding areas that offer abundant pollen and nectar (Aspelin Ramm, 2015).

2.3. Freshwater

Urban freshwater issues relate to direct human consumption, and water embedded in products (Norman & Steffen, 2018), as well as access, quality, and quantity management. A circular urban approach to water promotes water sensitive cities with a diverse and decentralised infrastructure (Wong & Brown, 2009). It entails recreating pre-development hydrological conditions (Parris et al., 2018) and protecting and regenerating rivers and other natural sources of water, using secondary sources, in addition to designing water efficient landscapes (Wild et al., 2020). Flood control and water purification through green infrastructures that reduce surface runoff, retain, and infiltrate water (Ely & Pitman, 2014), and filter diffuse pollution from urban surfaces (Wild et al., 2020). Moreover, constructed wetlands to treat wastewater through phytoremediation processes (Polomski et al., 2007) for reuse.

In São Paulo, Brazil, the Programa Gentileza Urbana (Urban Kindness Programme) uses green infrastructure interventions (Figure 6) to improve permeability in a city constantly battered by floods. According to A. Graziano (personal communication, March 8, 2021), in the period 2019–2020, of the 101 interventions (136,024.00 m^2), 65 were raingardens and bioswales, and three conservation woods. The success of the initiative seems to have inspired the city Climate Action Plan, which included nature-based solutions as a strategy to improve stormwater management (Prefeitura do Município de São Paulo,

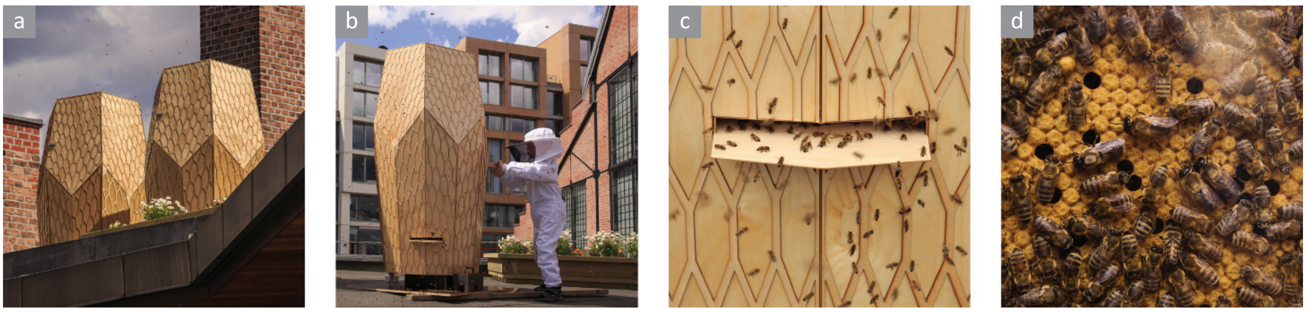

Figure 5. Vulkan precinct in Oslo: (a), (b), (c), and (d) beehive designed by Snøhetta. Source: Photos by Morten Brakestad (2016).

Figure 6. Programa Gentileza Urbana: Interventions in São Paulo; (a) overview of street with rain gardens; (b) a raingarden at the intersection of two streets; (c) kerb detail for water flow.

2021). Moreover, its focus on public areas functions as a complement to the existing "environmental quota" planning instrument aimed only at building plots over 500 m^2: Similarly to Malmö's green space factor, the quota requires new construction projects to achieve a minimum score based on the implementation of green infrastructures to improve local water management, microclimate improvement, and vegetation enhancement (Silva et al., 2017).

2.4. Nutrient Flows

Linked to intensive fertiliser use in crops and water bodies' eutrophication, phosphorus and nitrogen are essential for ecosystem productivity and food production (Steffen et al., 2015). Cities' impacts relate to the increasing consumption of food and nutrient flows into receiving waters (Norman & Steffen, 2018).

Measures include local organic agriculture and closing the loop of nutrients through recovery and management. As the uptake from the atmosphere is limited, one can cultivate nitrogen fixing crops, as legumes, in community gardens (Mendonça et al., 2017). Both nutrients can be recovered from wastewater treatment with constructed wetlands (Polomski et al., 2007), strategies that could be boosted with a georeferenced identification of hotspots for intervention (Wielemaker et al., 2020). The use of compost from organic waste promotes nutrient cycling (Shrestha et al., 2020) in urban and rural agriculture; however, rooftop farming requires extra attention to reduce nutrient loss to storm drains (Harada et al., 2018).

2.5. Natural Resources

In addition to circular design principles (Zimmann et al., 2016) for the biological and technical cycles of resources, bioconnections to reduce the material footprint and improve resource use include:

- Regenerative and circular procurement guidelines (Volans, 2020);
- Sustainable sourcing of biological and technical resources, as mining has large impacts on rainforests (Sonter et al., 2017);
- Prioritise biobased alternatives as wood and bamboo (Churkina et al., 2020), mycelium and hempcrete (Blok et al., 2019), and plant-based alternatives to animal leather;
- "Industrial symbiosis" through infrastructure sharing or exchange of by-products (Rosado & Kalmykova, 2019);
- Long-term resource planning through buildings as materials banks and materials passports for resource traceability (Debacker & Manshoven, 2016), and trade of recovered products using digital marketplaces.

2.6. Outdoor Environmental Quality

Outdoor environmental quality is about the various outdoor aspects which "which have an impact on the health, comfort or wellbeing of the occupants and neighbours" (HKGBC, n.d.). Here, it is explored through six parameters: air quality, thermal comfort, soundscape, visual comfort, proxemics, and beauty & quality, defined below.

Although DE normally depicts health separately, here we see it as a result of outdoor environmental quality and other ecological and social boundaries under the lenses of positive health, drawing upon six pillars: mental wellbeing, meaningfulness, quality of life, social-societal participation, daily functioning, and bodily functions (Institute for Positive Health, 2017). As compiled by van den Bosch and Ode Sang (2017), there is extensive research and evidence that nature-based solutions may influence health through many physical and mental variables.

2.6.1. Air Quality

Air pollution is one of the biggest urban threats to health. Although it needs to be solved at the source, plants have a cleansing ability by retaining, absorbing, and transforming pollutants in the air, soil, and water (Dicks et al., 2020). Different green infrastructure elements and configurations, however, offer different capabilities that need context-based consideration (Abhijith et al., 2017). Take moss, for instance, and its relatively high potential for air pollutant removal (Donateo et al., 2021), as the structure installed in London (Figure 7). Vegetation

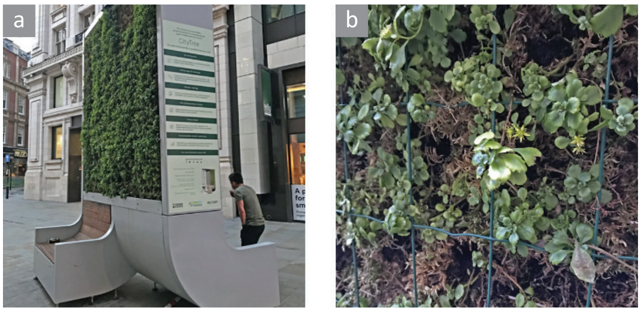

Figure 7. CityTree moss vertical infrastructure in London: (a) general view; (b) detail of moss and plants arrangement.

selection for green infrastructure, nonetheless, needs attention to avoid some potential associated disservices related to pollen and the emission of biogenic volatile organic compounds by some species that react with NOx and solar radiation, creating ozone and deteriorating air quality (Leung et al., 2011).

2.6.2. Thermal Comfort

Urbanised environments tend to be warmer than their rural surroundings due to the urban heat island effect (T. R. Oke, 1978). This phenomenon, intensified by climate change, harms health, and increases energy consumption for building cooling (Santamouris, 2014). The benefits of bioclimatic architecture and urban design integrated with green infrastructure, and the resulting microclimate modification ecosystem services are widely known (Battisti, 2020). However, the wide continuum of green infrastructure typologies, from green open spaces to water bodies, to tree canopies, as well as green roofs and vertical greenery systems (Bartesaghi Koc et al., 2017) leads to diverse effects, requiring a context-based look in each intervention.

2.6.3. Soundscape

When looking into acoustic issues, we usually emphasise the reduction of noise nuisances in built environment, rather than designing high-quality soundscapes that could positively impact our perception and understanding of the acoustic environment (International Standard Organisation, 2014). Through adequate design, vegetation may provide benefits as insulation and sound scattering (Yang et al., 2013), and natural sounds may generate a pleasant acoustic environment, mask noises, and contribute to stress reduction (Semidor & Venit-Gbedji, 2009).

2.6.4. Visual Comfort

Visual comfort may be disrupted by the excess or lack of light during day or night in various situations. Glare, for instance, may be reduced or eliminated with adequate positioning of vegetation barriers and surface covering (Kocur-Bera & Dudzinska, 2015).

2.6.5. Proxemics

Proxemics, "the study of man's perception and use of space" (Hall et al., 1968, p. 83), is linked to bioconnections through the design and organisation of nature in public areas that adds variety and options to facilitate citizens' interaction or isolation. During the Covid-19 pandemic, the need for accessible green infrastructures, in which contact with nature while maintaining social distancing is possible, grew stronger, indicating different types, sizes, and uses of green infrastructures are needed (Ugolini et al., 2020).

2.6.6. Beauty and Quality

Beauty, seen in the "Living Community Challenge" scheme not from a single perspective imposed onto others, but as an acknowledgement of its diverse possibilities, is "a precursor to caring enough to preserve, conserve and serve the greater good" (International Living Future Institute, 2017, p. 53). The scheme suggests, as one of the strategies, the presence of art installations in public spaces. The consideration of available views, materials used, water fountains, and other visual elements, in addition to year-round vegetation (Knobel et al., 2021), as well as varying degrees of tamed or wild landscapes (WHO Regional Office for Europe, 2016), also impacts the perception of beauty.

Regarding quality, in addition to adequate maintenance and perceived level of fauna and flora biodiversity (WHO Regional Office for Europe, 2016), B. Chen et al. (2009) suggest factors as varied as auditory, olfactory, tactile, and visual elements should be considered. Du et al. (2016) indicate the diversity of vegetation structure and height, the presence of dominant trees, planting density, colour contrast, and species number. Finally, de la Barrera et al. (2016) imply beauty depends on the green infrastructure size, shape, and vegetation cover.

2.7. Food

Food production is strongly dependent on rural areas. Organic urban farming on public and private land, abandoned areas, and horizontal and vertical surfaces (Parris et al., 2018) could reduce this dependency and facilitate access to healthy food, reducing food poverty, and increasing food security, particularly in face of extreme events. A regenerative and circular urban approach to food promotes healthier lifestyles, encourages community engagement (Enssle & Kabisch, 2020), reduces waste, and regenerates natural cycles (Raworth, 2017) through composting, biogas production, and synergies with pollination (Ellen MacArthur Foundation, 2019).

An ecological favela may seem like an oxymoron, but the history of Vila Nova Esperança, an informal settlement in São Paulo, exemplifies the power of nature and local food production. The community avoided expropriation through their environmental approach to land (Figure 8): an organic food garden for all residents, a community centre with a collective kitchen, and interventions to reduce geological risks. These are some of the actions strengthening community engagement and regeneration of an underprivileged area, generating benefits to their daily lives in what they now consider an "ecological village" (L. Esperança, personal communication, November 29, 2019).

2.8. Local Economies

A regenerative and circular economy sees businesses as nodes of a complex value network (Volans, 2020) that offers more than just products and services (Driesenaar, 2019). They foster distributive and local economies (Raworth, 2017) that create positive impacts on nature and communities. Expanding on Samset and Accorigi (2020) and Taylor Buck and While (2021), an "urban circular bioeconomy" can be understood as the valorisation of primary and secondary biological resources in cities in the form of services and products that generate direct and indirect benefits to the economy and the society in the present and future.

This could be achieved through food gardens with free or low-cost access to the production and space, produce selling in local shops and marketplaces at fair prices, besides jobs for the maintenance of green spaces. Waste and resource exchange through "industrial symbiosis" could also connect local producers (Rosado & Kalmykova, 2019). Indirect contributions to local economies may come through the ecosystem services valuation of urban green infrastructure (Elmqvist et al., 2015) that could support financial mechanisms as green or climate bonds (Bernknopf & Broadbent, Craig, 2020) and improve green property taxes. Regenerative and circular neighbourhoods could also boost the local economy by attracting tourism (Parris et al., 2018). Given the possibility of green infrastructures raising the price of properties (Swinbourne & Rosenwax, 2017), careful attention must be given to avoid gentrification processes (Ehrmann, 2018).

An "open-source circular design," in which a collaborative, shared, and transparent development and use of ideas merged with the principles of circular economy (Open Source Circular Economy Days, 2016) has the potential to decentralise the design and production of goods, facilitating a distributive economy that emphasises local businesses rather than big corporations (Raworth, 2017).

2.9. Society and Governance

Different boundaries as social equity, social networks, political voice, and access to infrastructures may be merged under the umbrella of society and governance. There are two important aspects to foster those different issues; one is about planning cities for all and by all—i.e., considering that cities should be for all citizens, and more than that, engaging the different social groups in this process. Another aspect is access to all basic infrastructure, which includes nature, or green infrastructure. Normally the main indicator considered in some municipalities, access is an important factor towards urban green equity (de la Barrera et al., 2016; Nesbitt et al., 2018), and WHO Regional Office for Europe (2016) suggests residences should be located within a 300 m linear distance, or 5 min walking, from a green space.

The strengthening of social networks and cohesion has been associated with green infrastructures, particularly for older citizens, and can be enhanced by ensuring "universal design" and spaces for different age groups (Enssle & Kabisch, 2020). Adequate engagement of citizens and participatory governance is essential to ensure political voice (Nesbitt et al., 2018). One example is the City of Melbourne (2017) "urban forester" programme,

Figure 8. Vila Nova Esperança, São Paulo: (a) community leader Lia Esperança in the organic food garden; (b) greenhouse; (c) slope intervention.

which engages citizens in the development of science through data collection, planning, and other initiatives.

3. Discussion

We prepared a framework summarising relevant bioconnections for each social and ecological boundary (Figure 9) discussed above. On close examination, the multidimensional effects of their ecosystem services across boundaries become clear. This reflects the multifunctional roles of green compared to hard infrastructure (Ely & Pitman, 2014), and the inherent systemic nature of regenerative design and circular economy There are cases, however, where a mixed green–grey infrastructure delivers optimised outcomes to increase resilience (Ely & Pitman, 2014). More than just benefits for human society, they have potential to produce a positive impact to both human and the planet in the short and long-term. Nevertheless, careful planning and design of solutions is needed to avoid potential disservices or ineffectiveness (Leung et al., 2011; van den Bosch & Ode Sang, 2017). This "systems thinking" also translates in the need to engage different sectors and actors, as collaboration is a key concept to circular economy (Ellen MacArthur Foundation, 2019). In that matter, and in line with society and governance, evidence suggests that reduced or no engagement from communities in decision-making processes may lead to poorer results of interventions (Roe et al., 2021).

New neighbourhoods, like Bo01, demonstrate the significance of putting bioconnectivity at the core early in the process. Initiatives like Gentileza Urbana showcase

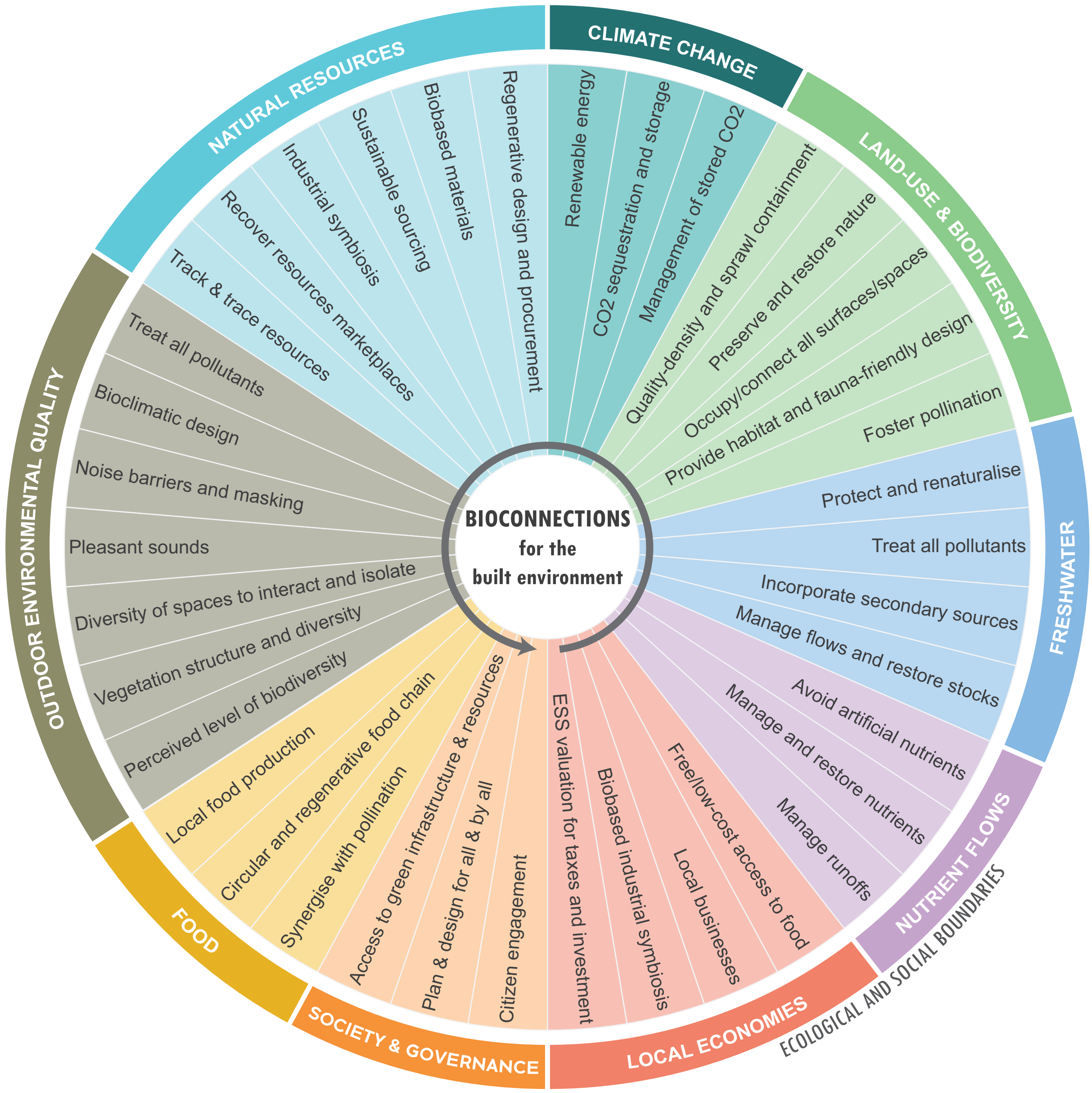

Figure 9. Bioconnections framework for ecological and social boundaries under a regenerative and circular approach for the built environment.

the potential to regenerate the building stock of our cities and open the discussion about high-quality densification and green areas, so that we reach a balance and start reconverting urban voids and underutilised buildings and urban spaces. In any case, policies are important enablers to define the rules and implement financial incentives to initiate implementation.

From an economic point of view, the World Economic Forum indicates that a nature-focused approach to cities could generate US$3 trillion of annual business opportunities and 117 million jobs by 2030 (World Economic Forum, 2020). Bioconnections have the potential to bring nature into cities, increasing resilience, and providing liveable urban spaces with a positive impact on health and social aspects.

4. Conclusions

In this article, we have argued that the current linear approaches to sustainability are not enough in light of the environmental and social challenges of cities. Acknowledging the importance to learn from nature and its multidimensional benefits to both natural and human-made environments, we proposed the adoption of bioconnections as enablers of a "regenerative circularity" for the BE. Reinterpreting the DE of ecological and social boundaries (Raworth, 2017) for a built environment context, we examined and discussed the literature to identify relevant interventions, solutions, or strategies. A resulting bioconnections framework was prepared to illustrate the wide range of possibilities that could facilitate the transition to regenerative and circular cities, hence, seeking to address Buchmann-Duck and Beazley (2020) call for a stronger biodiversity inclusion in circular economy studies. Global examples of green neighbourhoods and interventions demonstrated the technical feasibility of implementing bioconnections and the importance of policies to foster nature-focused interventions in cities, as argued by Parris et al. (2018).

One should have in mind the impossibility of fully restoring urban areas and their urban biodiversity to a pre-development condition. Regenerating is not about a return to a nostalgic past, but rather about creating a new and generous future in which, in symbiosis with nature, we create value and positive impact for the planet and its human and non-human inhabitants. Hence, the increasing need to incorporate nature's knowledge as a tool to improve urban areas and address the increasing social and environmental challenges. As we enter the "decade (2021–2030) on ecosystem restoration" (United Nations, 2019), that becomes increasingly imperative. In that light, the contribution of this article is twofold:

a. It presents a nature-based response to the PB and DE models of ecological and social boundaries from a local scale and built environment perspective;
b. It offers a bioconnections framework for the development of new urban areas or transition of existing ones under regenerative and circular lenses.

Future research could benefit from a more in-depth examination of how local policies may hinder or foster bioconnections and how they incorporate ecological and social boundaries. Defining indicators may also support measuring the actual contribution of the proposed solutions both in isolation and combined, particularly to better understand their synergies and trade-offs.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

Context-Specific, User-Centred: Designing Urban Green Infrastructure to Effectively Mitigate Urban Density and Heat Stress

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Abstract
Green infrastructure plays a vital role for cities facing the challenges of urbanisation and climate change. It has the potential to mitigate the adverse effects of urban density and the heat island effect, enhancing the ecological and social resilience of cities and their inhabitants. This study identifies contextual, psychological, and social factors which influence people's subjective evaluation of urban green infrastructure (UGI), density, and heat stress. Planning recommendations for effective, context-specific, user-centred design are developed to increase the social and health benefits of UGI in limited space. To do so, a mixed-methods approach that combines social surveys, GIS-analysis, and microclimate modelling was employed. The field studies were undertaken in two contrasting neighbourhoods in Munich, Germany: a densely built and scarcely vegetated inner-city neighbourhood and a declaimed "green and compact" neighbourhood at the outskirts. Both sites are assessed in terms of their supply of green infrastructure, building and population density, and outdoor summer heat loads drawing on geostatistical data and mean radiant temperature modelling. This assessment is compared to the inhabitants' subjective evaluation thereof retrieved from face-to-face questionnaires, and semi-standardised interviews. The results indicate that the existence and the amount of UGI per se are not decisive for people's perception of urban heat, density, and neighbourhood attractiveness. It is rather the perceived accessibility of green spaces, their design, quality, and contextual factors like traffic or the presence of other people that define its value for urban dwellers.

Keywords
crowding; mental maps; neighbourhood quality; outdoor thermal comfort; psychological evaluation; UGI; urban density; urban stress; urban vegetation

Issue
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1. Introduction

Adapting to climate change while addressing increasing housing demands is among the key challenges for growing cities in the fight against urban sprawl (Wolff & Haase, 2019). Climate change exacerbates the urban heat island effect (Chapman et al., 2017) and increasing densification is reducing unsealed and green urban areas (Haaland & van den Bosch, 2015). However, research has shown that urban green infrastructure (UGI) does not only lower urban heat levels through shading and evapotranspiration (Bartesaghi Koc et al., 2018) but provides further ecosystem services and enhances social resilience (Bowler et al., 2010; Rall et al., 2017). To exploit the full potential of UGI for residents and enhance adaptation capacities, a context-specific and user-centred design focus is necessary (Hansen & Pauleit, 2014; Klemm et al., 2017). Therefore, this article explores people's subjective evaluation of UGI in connection with density and heat stress.

1.1. Perception of Urban Density

Urban density is a complex phenomenon: In the "compact city" model of the European Commission, a high density of people, jobs, and dwellings is promoted to improve the environmental sustainability and liveability of cities (Commission of European Communities, 1990). Reduced commuter traffic, promotion of public transport, higher social interactions, reduced ground space per capita, and reduced emissions are seen as benefits of high-density cities (Jabareen, 2006). However, critics argue that fresh air, green space supply, and habitats for species are rather provided in lower-density cities (Neuman, 2005), and that a higher cost of land can lead to social inequities (Debrunner et al., 2020). In city planning, urban density mainly refers to building density (height, volume, and spacing) and population density (Cheng, 2010). The term "crowding" is used when density levels are evaluated as too high and a person experiences "sensory and social overload" (Rapoport, 1975, p. 134), a loss of control, or behaviour constraints due to density. Feelings of crowding can occur at very different density levels depending on the (social and material) setting, but also on the individuals themselves and their subjective evaluation of the situation. Cultural, emotional, contextual, and other factors influence whether dense settings are perceived as crowded and result in stressful experiences (Frerichs & Küpper, 2017; Rapoport, 1975). While certain characteristics of the built environment such as street width (Husemann, 2005), building coverage ratio or block size (Knöll et al., 2018) have been found to increase the feeling of crowding and urban stress, vegetation seems to have a positive effect on the evaluation of density. In a study by Husemann (2005), streets with trees were evaluated as less dense and less crowded than streets without trees. In a participatory study, Kyttä et al. (2013) observed that positively rated urban places had a significantly higher proportion of vegetation than negative ones and a lower building density. The interactions between different aspects of urban form and vegetation and their effects on people's perception of density and crowding still remain rather unclear (Knöll et al., 2018). In this regard, more empiric research focusing on people's evaluation of "real" complex urban environments has been called for to gain a deeper understanding of the dynamics involved.

1.2. Outdoor Thermal Comfort and Urban Vegetation

As excessive heat negatively affects human health (Lau et al., 2015), heat stress has become an increasing concern for urban planners, especially against the backdrop of climate change and already elevated urban temperatures (Chapman et al., 2017). Several thermal indices have been developed for the investigation of human thermal comfort, such as physiological equivalent temperature and the universal thermal climate index (Staiger et al., 2019). Microclimatological studies have found that UGI and especially trees can significantly improve human thermal comfort. Large, dense trees reduce daytime air temperature by up to 3°C and physiological equivalent temperature directly beneath tree crowns by up to 16°C (Lee et al., 2020).

However, findings from environmental psychology suggest that despite being exposed to the same environmental conditions, thermal sensations of people differ (Nikolopoulou & Steemers, 2003) and that subjective thermal preferences might even contradict physical conditions: Comparing different street designs, Klemm et al. (2015) found that people felt more comfortable in a street with small trees and front gardens than in a street with tall trees, even though the latter showed lower physical heat stress. According to Nikolopoulou and Steemers (2003), the range of psychological factors influencing thermal comfort includes naturalness (degree of artificiality), expectations, former experience, time of exposure, perceived control, and environmental stimulation. Furthermore, the duration of experience influences the thermal perception of a specific site (Klemm et al., 2015). Overall, the psychological impact of urban green spaces on people's perceived thermal comfort remains a relatively unexplored research topic (Klemm et al., 2015).

Thus, this article investigates the interactions between density, heat, and vegetation from a user perspective. By comparing their objective assessment with people's subjective evaluation, we can pinpoint parallels and disparities, exploring factors that influence the perception of the urban environment.

2. Methodology

We employed a mixed-methods approach that combines surveys, GIS-analysis, and microclimate modelling to analyse the evaluation of heat, density, and urban vegetation (Figure 2). The field studies were undertaken in two contrasting neighbourhoods in Munich, Germany.

2.1. Study Areas

The study site is Munich, one of the fastest-growing and densest German cities (Landeshauptstadt München, 2018). Two contrasting neighbourhoods were selected: a densely-built and sparsely vegetated inner-city neighbourhood (Bahnhofsviertel), and a more sparsely built neighbourhood with ample green infrastructure at the outskirts (Messestadt; Figure 1). The Bahnhofsviertel, located directly south of the Munich central station, is not only a transportation hub, but also attracts a diversity of people and businesses. Sporting many small international shops, services, hotels, offices, and several university and medical facilities, the streets are usually bustling with people while at the same time being home to only 5,685 residents. Unlike the Bahnhofsviertel, which has grown and evolved over time, the Messestadt has been planned from scratch as a sustainable residential area on a former airport site at the eastern outskirts of Munich. It was designed in the 1990s with reduced traffic loads, a large landscape park, and is home to 11,895 people from more than 100 nationalities.

2.2. Objective Evaluation

2.2.1. Geostatistical Analysis of Urban Vegetation and Density Parameters

Urban density was analysed based on the data provided by GeodatenService München (2020) from Munich's official city map (*Stadtgrundkarte*) using GIS. The floor area ratio was calculated as the total gross floor area (ground floor area multiplied by the number of floors) of all buildings divided by the block area for each city block. As additional parameters for urban density, building coverage (residential/non-residential), traffic areas, and public green space were analysed. Information on the quality of other surfaces (sealed/non-sealed, green/non-green) was obtained from raster data in the European Settlement Map (2017). To determine tree coverage, data on tree cover from satellite data from the Street Tree Layer (2018) were used. Population density (i.e., number of residents) was determined based on 100 m × 100 m raster data from ZENSUS (2011), as the most current dataset available.

2.2.2. Modelling of Mean Radiant Temperature With SOLWEIG

Outdoor human thermal comfort was assessed with the solar flux model SOLWEIG (Lindberg et al., 2018). SOLWEIG has been applied in various microclimatological studies to determine the mean radiant temperature (T_{mrt}; e.g., Jänicke et al., 2016; Lau et al., 2015). In Central Europe, T_{mrt} is the dominating factor for outdoor human thermal comfort if a cloudless, summer day is considered (Lee & Mayer, 2018). As a representative for a severely hot day, the 25th July 2019 (T_{max} > 30°C, T_{min} > 20°C, wind speed below 2 m/s) was selected for the simulation study. The required meteorological input data was provided by the Meteorological Institute Munich (2018). Its weather station is located in the city centre of Munich (distance to study areas: 8.7 km to Messestadt, and 1.7 km to Bahnhofsviertel). High-resolution digital elevation models, land cover data, and colour-infrared imagery to identify vegetation used for the model set-up were provided by the Bavarian State Office for Survey and Geoinformation (2018). As a compromise between accuracy and modelling time, we set the pixel resolution to 2 m. We analysed the simulation outcomes for 2 pm, as this represents the hour with the maximum human heat stress.

2.3. Subjective Evaluation

2.3.1. Questionnaires on Neighbourhood Quality and Public (Green) Spaces

Face-to-face questionnaires were conducted in both neighbourhoods in July 2019 (Bahnhofsviertel: n = 76; Messestadt: n = 68; for detailed sociodemographic information see Table S1 in the Supplementary File). To ensure the representation of a diversity of people, spaces, and atmospheres, the questionnaires were conducted in seven different locations within each neighbourhood (including green spaces, public squares, main and side streets) on all days of the week and at different times of the day. Only warm, sunny days (23–30°C) were selected for the surveys. In the questionnaire, the participants were presented with a polarity profile, which they were asked to use to describe the neighbourhood (see Figure 5 here and Questionnaire S2 in the Supplementary File). The profile was guided by Kyttä et al. (2013) and based on criteria of applicability and comprehensibility (even for non-residents). Moreover, respondents were asked to spontaneously name places in the neighbourhood that they experienced as pleasant or unpleasant on hot days (free mentions). If respondents were residents of the study area, they were also asked if they would like to participate in an in-depth interview.

2.3.2. In-Depth Interviews and Mental Mapping

This way, we were able to recruit a random sample of 28 residents (Bahnhofsviertel: n = 11, Messestadt: n = 17) for semi-standardised interviews with a duration of 40 to 90 minutes (for sociodemographic characterisation see Table S3 in the Supplementary File). Interviews were recorded, transcribed, and analysed using qualitative data analysis software. The interviews expanded on the answers in the short questionnaire and additionally explored the topics of neighbourhood atmosphere, social cohesion, identification, public (green) spaces, and residential quality. In the interviews, participants were also shown an aerial photograph of their residential area and were encouraged to talk about their everyday activities and mark corresponding routes and locations on the map. To capture thermal comfort conditions in the neighbourhoods' public space, participants marked areas or locations according to their thermal comfort qualities with sticky dots on the map: green dots for places that they generally perceived as pleasant on hot days (> 30°C), red dots for unpleasant ones, and yellow dots for "in between" sensations. In contrast to other ther-

Figure 1. Pictures of distinctive sites of the study areas Bahnhofsviertel (B1–B3) and Messestadt (M1–M4), and their location within Munich.

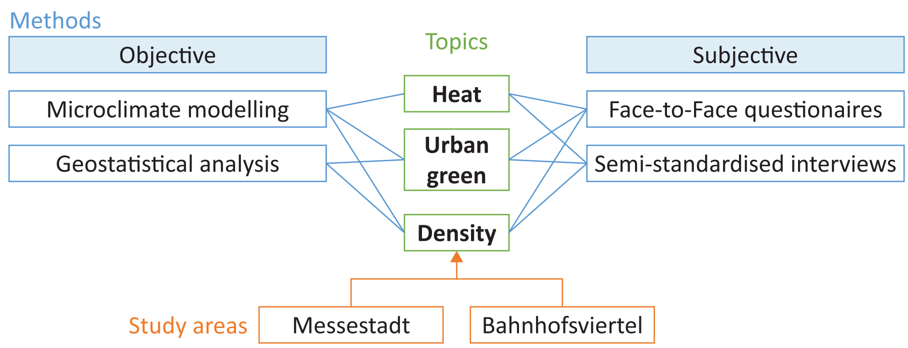

Figure 2. Employed methods and research approach.

mal comfort surveys, which usually focus on right-here-right-now evaluations of current micro-meteorological parameters (like air temperature, sun, humidity, and wind), this mental mapping method allowed us to capture people's long-term memory of holistic thermal perception. All dots were digitised and geocoded using a GIS. Dots referring to larger areas or streets were polygonised. Based on the resulting layers of dots, coloured heat maps were created using Kernel density estimation with a radius of 15 m (Netek et al., 2018).

3. Results

3.1. Density and Vegetation

3.1.1. Objective Assessment of Density and Vegetation

The study area Bahnhofsviertel consists of 35 building blocks which are dominated by four-storey block perimeter construction of mixed ages. Green infrastructure is scarce in the neighbourhood (11%; Figure 3). The study area comprises a small park with many trees (see B3 in Figure 1) and part of an open area (B2) which is empty except for events and rimmed by a tree promenade with benches and playgrounds. Within Bahnhofsviertel itself, though, only the southern streets are lined with trees, and backyards are mainly sealed (94.4%).

Messestadt consists of 48 building blocks featuring mainly three to six-storey apartment buildings (row houses), some perimeter apartment blocks, and some (semi-)detached housing. South of Messestadt is a large park (M3), with a small forest and a swimming lake (M4), connecting the neighbourhood to the surrounding rural zone, only a very small part of which is comprised within the study area. There are several "green links," with playgrounds interlacing the residential area with the park. Although all streets are lined with trees, only tall ones or tree groves appear on the map (Figure 4). Within the residential area, most backyards are green, and buildings on average account for only 43% of the block surface.

With a floor area ratio of 2.7, Bahnhofsviertel is almost twice as densely built-up as Messestadt with a floor area ratio of 1.4. Despite this, the population density in Bahnhofsviertel is rather low, with 66.3 residents per ha. The opposite is true for the residential district Messestadt, whose population density is 117.7 residents per ha.

3.1.2. Subjective Evaluation of Density and Vegetation

As the neighbourhood evaluation shows (polarity profile; Figure 5), the objective assessment of green infrastructure supply and density is well reflected by people's subjective perception. Messestadt is generally perceived as much greener, more relaxed, quiet, and also safer than Bahnhofsviertel, which in turn is rated rather unpleasant, unattractive, and neither bike-, car-, child-, or senior-friendly.

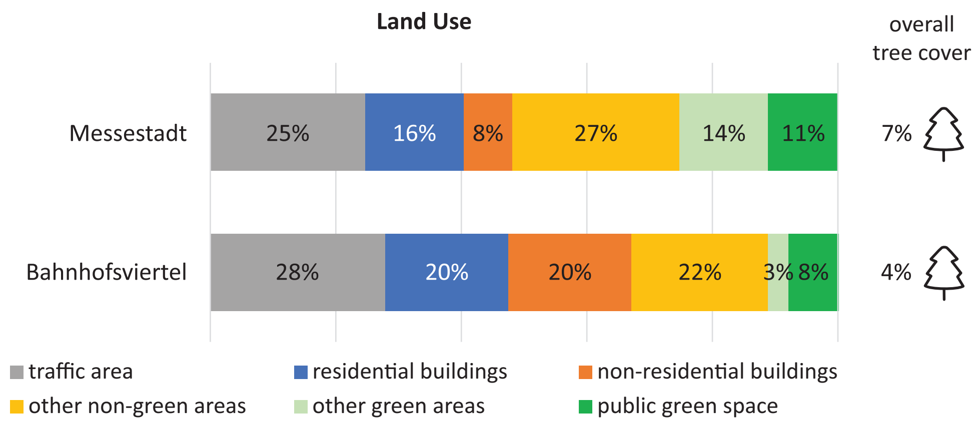

Figure 3. Land use for the study areas of Bahnhofsviertel and Messestadt.

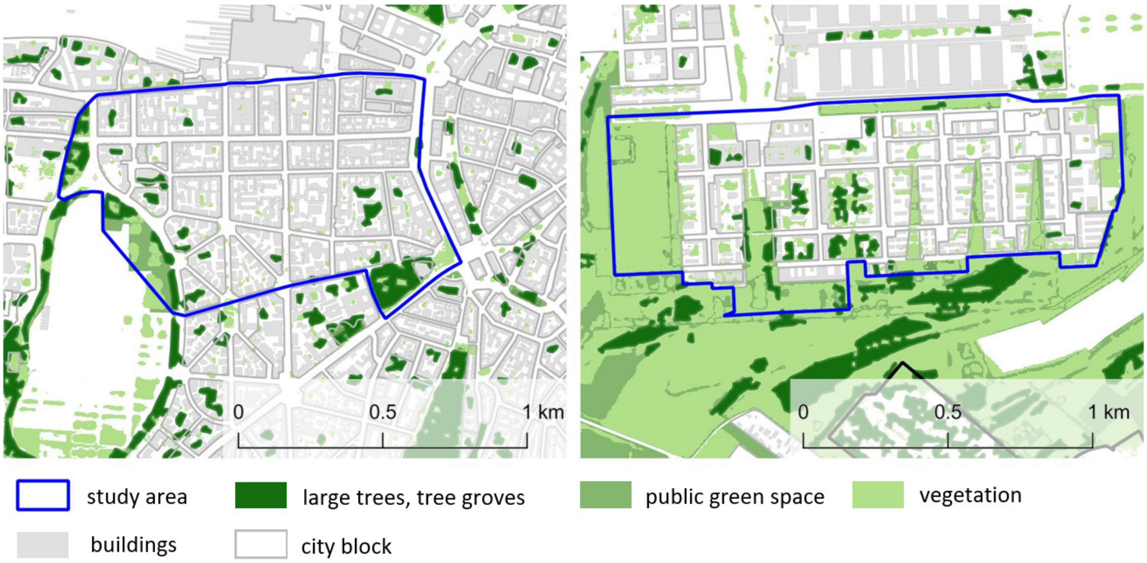

Figure 4. Vegetation within and around the study areas of Bahnhofsviertel (left) and Messestadt (right). Sources: treecover from Street Tree Layer (2018), vegetation from European Settlement Map (2017), city structure from GeodatenService München (2020).

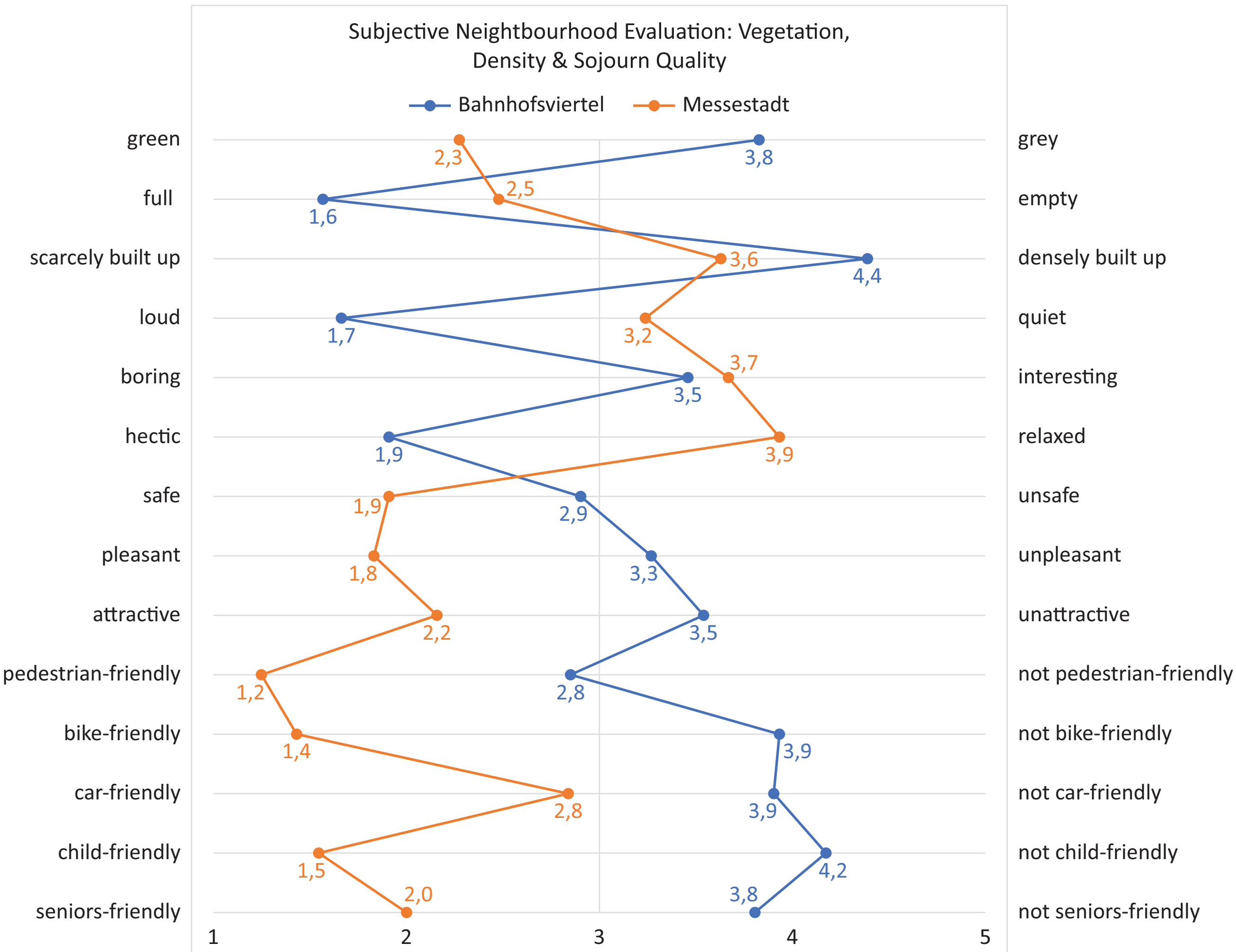

Figure 5. Polarity profile: Subjective evaluation of Bahnhofsviertel (blue) and Messestadt (orange).

Statistical analysis (Table S4 in the Supplementary File) reveals highly significant correlations between the evaluation of greenness and other items of the polarity profile across both neighbourhoods. Respondents who evaluated their neighbourhood as greener tended to also perceive it as less densely built-up and more pleasant. They also rate their neighbourhood more positively on all other items with the strongest correlations for child- and senior-friendliness, and relaxation. We also found differences regarding the evaluation of density, greenness, and quality of stay between social groups. In both Messestadt and Bahnhofsviertel, residents, in comparison to non-residents, gave "better" ratings for all items except emptiness and safety. Non-native speakers perceived the quarters as less densely built-up and more attractive than native speakers. Also, age seems to make a difference: Participants aged 30 or less generally perceived the neighbourhoods as more pleasant, more relaxed, and—marginally significant—not as densely built-up.

The perceptions of density and vegetation were explored in more detail by the in-depth interviews. This quote by a Bahnhofsviertel resident reflects the general impression of most respondents: "It's brutally dense… every square meter is utilised" (Jürgen, 55). There is noise and bustle on the streets, and especially the heavy car traffic and lack of space contribute to feelings of crowding and stress for many respondents: "Of course, that makes it exhausting sometimes because the streets are crowded, people do what they want, there's criss-cross parking in front of the supermarkets and there's no getting through, the sidewalks are full" (Rebecca, 28). However, this density can also be experienced as positive and stimulating: "It's unbelievably narrow, unbelievably dense… everything is quite compact as if you were to press everything together in a ball. Of course, that's also what makes it so appealing, there's an incredible amount of life in it" (Theodor, 51). Street greenery of any kind seems to be the remedy of choice for Bahnhofsviertel residents: "Here [in the southern part of the neighbourhood] it is much greener… when I look out of the window, I could just as well be in the countryside. So that's an enormous relaxation for me….I also think that other people feel less stressed" (Jürgen). The positive psychological effect of vegetation in reducing feelings of crowding and stress is experienced and voiced by almost all respondents: "I think greened streets would definitely help me [to cope]—at least visually" (Micha, 32). One resident, however, voiced objections to planting trees in one of the main streets in the neighbourhood to preserve its historical axis. The large open space Theresienwiese (B2) is an important counterpoint to, and a pleasant relief from, the crowded streets: "When I go grocery shopping, I stop there and sit down. I get to talk to nice people there, but I also find it pleasant in that it's such a wide area. It's soothing to the eye, no advertising" (Rainer, 60). The space's dimensions significantly contribute to its high quality of stay and its function as a social meeting point: "One of my favourite spots is on the steps at the edge of the Theresienwiese, because you simply have this expanse….You take a bottle of wine with you and share it with your friends and look into the distance'' (Micha).

In stark contrast to Bahnhofsviertel, in Messestadt there seems to be almost too much space. While the residents appreciate the low building density of their neighbourhood as a pleasant luxury, the street space (M2) is predominantly perceived as large, monotonous, and characterised by a lack of vegetation: "They have extremely wide sidewalks… there is simply far too much paved area" (Martin, 65). Another resident describes, "in fact, that's very brutal if you look along the streets. There are these concrete walls everywhere that separate the front gardens [from the street]. And if they are not greened, then it is simply brutal" (Anke, 47). A woman who has lived in the neighbourhood for many years admits that she sometimes still gets lost because the streets and the "white sterile building blocks" look so similar. Also, Willy-Brandt-Platz (M1), a large open square at the entrance to Messestadt is perceived by almost all respondents as far too big: "That's the main problem. The square is much, much too big for its function. It has no function" (Thomson, 45). Most would prefer greening the square with planters, arbours, or climbing plants that "would kind of make the space not seem so infinite" (Gertrud, 66). Interestingly, in Messestadt feelings of crowding are only experienced in the park, more precisely at the swimming lake (M4), which is "a people magnet." Most interviewees feel very much attached to "their lake," which, to them, is the biggest asset of the neighbourhood. It serves important social functions, especially for teenagers: "Apart from the lake, there's really no such thing as a real place for me to stay away from home" (Leopold, 14). The remaining "empty" space of the 210-ha park, however, is heavily underused: "On the meadows, there is hardly anyone….I think one prefers sitting down at a lake to somewhere where there is nothing" (Darian, 48). One teenager even suspects that "you are not allowed to go into the meadows" (Leopold). The "generous" supply of (semi-)private green space (e.g., backyards and gardens) further decreases residents' need to use the public park.

In summary, the street space in Bahnhofsviertel is perceived as narrow and crowded, while in Messestadt streets and sidewalks are very wide and at the same time experienced as rather empty. Public spaces in both neighbourhoods seem to have a rather low quality of stay, though for contrasting reasons. In Bahnhofsviertel, this is mainly due to heavy car traffic, feelings of crowding, or lack of safety; in Messestadt, it is more due to the missing street life and poor architectural design, which is considered "boring." A key factor in both cases is the perceived lack of vegetation which people seem to crave as relief from both too much and not enough urban density. In high-density settings, street greenery can create an atmosphere of relaxation and can bring relief from sensory overload. Where density is too low, vegetation can create a comfortable feeling of enclosure and can be a stimulating visual variation.

3.2. Heat Load and Vegetation

3.2.1. Objective Assessment of Heat Load and Vegetation

In both neighbourhoods, the most uncomfortable areas with the highest T_{mrt} values at 2 pm are found in locations without shade (Figure 6). Thorsson et al. (2014) proposed a threshold of 55°C for elevated and 59.4°C for extreme heat stress. Open spaces (B2, M1) and non-shadowed N–S running streets depict T_{mrt} values of 64°C and more. As the building structure in Messestadt is less compact than in Bahnhofsviertel, a larger fraction of the study area falls into the extreme heat stress category due to lack of shade (average T_{mrt} of 60.1°C for Messestadt, 56.4°C for Bahnhofsviertel). The most comfortable areas in both neighbourhoods are located in the shade of trees and buildings (T_{mrt} values from 35–40°C). The small forest in Messestadt M3 (mean T_{mrt} 35–37°C), the park in Bahnhofsviertel B3 (mean T_{mrt} 39–40°C), but also single street trees provide significantly reduced heat loads for residents. Heat loads and cool spots are not evenly distributed across the study areas. In Bahnhofsviertel, the north has higher heat exposure due to the absence of trees. In Messestadt, walkways and the southern meadows (M3) are exposed to heat and thermally uncomfortable.

3.2.2. Subjective Evaluation of Heat Exposure and Vegetation

The subjective heat maps (Figure 6) show that the most comfortably rated places coincide very well with the existing tree stock, whereas the open spaces and almost all streets are perceived as uncomfortable on hot days. This general observation coincides very well with the modelled thermal comfort. In Bahnhofsviertel, more than half of all respondents named "streets" as the most uncomfortable places, followed by the central station (17.1%) and the whole neighbourhood in general (7.9%; Table 1). Heat stress is highest where high density and lack of vegetation are combined with other heat exacerbating factors, like exhaust fumes. Feelings of crowding and perceived heat stress mutually reinforce

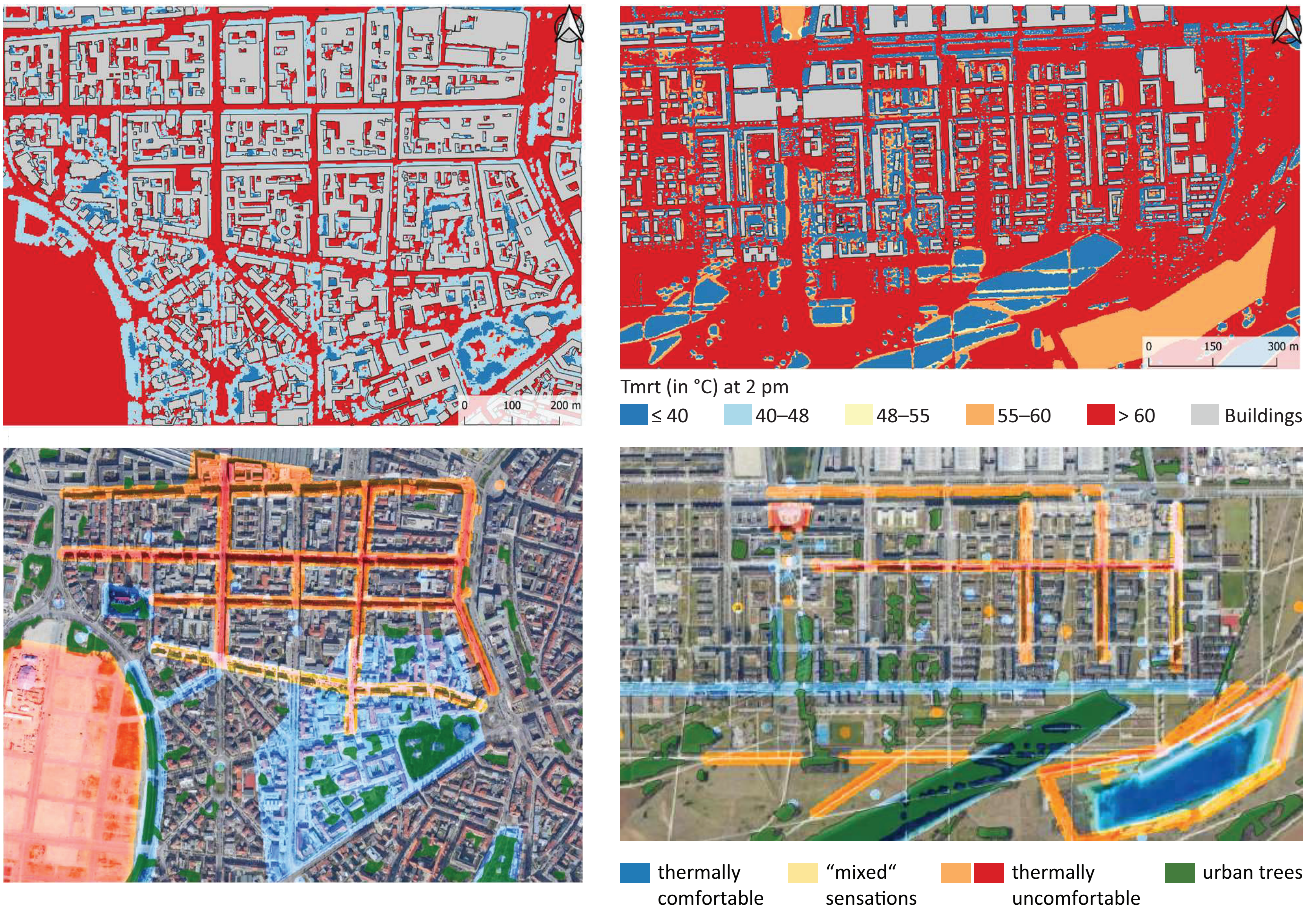

Figure 6. T_{mrt} model results for 25th July 2019 at 2 pm (top) and perceived thermal comfort maps (bottom) for Bahnhofsviertel (left) and Messestadt (right). The colour intensity in the subjective heat maps reflects the number of times the area or location was mentioned.

Table 1. Top three comfortable (left) and uncomfortable (right) sites in hot weather in each neighbourhood.

Messestadt: Top Three Sites Thermal Comfort (n = 68)		Messestadt: Top Three Sites Thermal Discomfort (n = 68)	
Swimming lake M4	54.4%	Willy-Brandt-Square M1	25.0%
Home/Private garden	30.8%	Streets (in general) M2	23.5%
Shopping mall	19.1%	Park M3	10.3%

Bahnhofsviertel: Top Three Sites Thermal Comfort (n = 76)		Bahnhofsviertel: Top Three Sites Thermal Discomfort (n = 76)	
Theresienwiese (area) B2	11.8%	Streets (in general) B1	51.3%
Nußbaumpark B3	10.5%	Central station	17.1%
Fountains	7.9%	Whole neighbourhood	7.9%

each other: "[This street] is such a narrow canyon of houses, or maybe I perceive it as much narrower on such a hot day" (Rebecca). The neighbourhood's compact building structure and narrow streets are, thus, a blessing and a curse at the same time. Narrow streets and tall buildings reduce sun exposure, while wider streets allow for the experience of cool winds and relief from crowded situations. This is also why the large open square Theresienwiese (B2) is the most frequently mentioned of comfortable places in Bahnhofsviertel (11.8%). However, in hot weather, people's use of the area concentrates at the partly tree-lined edges of the square. The Nußbaumpark (B3) was named most comfortable by 10.5% of respondents, followed by fountains in different locations (7.9%).

Conversely, in Messestadt, the site most often mentioned as uncomfortable in hot weather is the large open square Willy-Brandt-Platz (M1; 25%). "Streets" (M2) were named by 23.5% of respondents, followed by the public park (M3; 10.3%), and sports or playgrounds (7.3%). The experience of thermal discomfort in all these places is mainly attributed to a lack of shading trees. Existing trees are perceived as too small or even "puny" and the combination of street and building design reinforces heat stress: "Well, I think that the fact that there are so many white, large houses makes them very radiant. I definitely miss green there" (Maria, 22). One notable exception is a promenade that runs E–W and is lined with tall trees. Several interviewees related that this was always the road they chose on hot days, even if that meant taking a diversion. Notably, people experience heat stress even (and especially) in the park, mainly on the paths (M3), but also around the swimming lake (M4), because there is not enough shade. Nevertheless, the swimming lake is the place most frequently mentioned as pleasant on hot days (54.4%) and is also the only public outdoor space among the top three in the neighbourhood.

In both neighbourhoods, some places are shaded by trees and exhibit low levels of (subjective and objective) heat exposure but whose cooling function is neither used nor appreciated by most people because of their poor quality of stay. The park in Bahnhofsviertel (B3) is rated as a cool place on hot days; however, it is rarely used at all by respondents. Only 27.6% sometimes go there and only 14.5% of all respondents like spending time there. A resident of Bahnhofsviertel explains: "Why should I go there?... I wouldn't use the park... even though it is green, there is just not the atmosphere for me to relax like in a park" (Jürgen). One woman who lives in Bahnhofsviertel describes her feeling about the park as uncomfortable due to the design which is dominated by a lot of old trees and little open space: "Somehow, everything is so dark there. The paths cross each other, it's so opaque, for me there's just such a darkness attached to it that I really don't feel comfortable there and I actually even avoid it during the day" (Rebecca). Other interviewees refer to socially marginalised groups and alcohol and drug use in the park, which makes it unattractive for them. Most interviewees prefer visiting other, more attractive, green spaces instead and do not mind taking on longer journeys to get there. Likewise, in Messestadt, there is a tree-covered public square with some benches, which is evaluated as cool on hot days but is visited only infrequently: "In theory, there is shade, but it is just not comfortable there. I have never felt the impulse to sit down there," says Gertrud. Similarly, the small forest in the park could serve its function as a cool oasis amidst the heat-exposed grasslands if it were not considered hardly accessible, making it "a place for dogs rather than for people to stay'' (Maria).

In summary, the perception of heat stress in both neighbourhoods is influenced most by the supply or lack of shade, especially natural shade by trees. While there is no space for greenery in Bahnhofsviertel, the trees in Messestadt are too small to provide effective shade. Hence, in both neighbourhoods, streets, and most other public spaces are perceived as hot and uncomfortable in summer. This observation corresponds well with the simulation results. Not quite in accordance with the simulation, both parks and potential cool islands do not seem to play a crucial role in individual heat stress adaptation, as their design does not meet users' criteria. Also, Bahnhofsviertel is considered much more uncomfortable in hot weather than Messestadt, which is not supported by the simulation outcomes. This disparity is likely caused by traffic, people density, and visual building characteristics, which clearly influence people's heat perception, but have not been regarded in the objective heat assessment. Again, vegetation seems to have a positive impact on people's perception of heat that goes beyond its simulated cooling effect. We suggest that due to previous experiences and people's general knowledge that plants and trees provide shade and coolness, visual stimuli can provoke those very sensations. The same effect occurs with water. Where urban vegetation is scarce, water takes on an important cooling function, even if it is not "used" in a strict sense. Blue infrastructure (in our cases the lake and the fountains) seems to be able to compensate for the lack of green infrastructure, to some extent (Figure 7).

4. Discussion and Planning Implications

Our results support the idea that urban vegetation not only reduces objective heat loads but also reduces *feelings* of crowding and increases (thermal) well-being. This is in line with other studies that have found positive psychological effects of vegetation for thermal comfort (Klemm et al., 2015; Nikolopoulou & Steemers, 2003), urban stress (Kabisch et al., 2021; Knöll et al., 2018), and health (Kondo et al., 2018).

Depending on the density context, large open public (green) spaces can create an uncomfortable atmosphere of desolation or pleasant sensations of spaciousness and relaxation. Our results indicate that vegetation enhances the quality of stay in low-density settings, which to our knowledge has not yet been investigated in detail and is worth further research. Large open spaces or wide streets in low-density neighbourhoods were often perceived as uncomfortable, which is supported by other studies like Knöll et al.'s (2018), or Kaspar and Bühler's (2009), who found that visual openness is related to higher perceived urban stress and relate it to feelings of exposure. In such sites, vegetation or even additional construction could supply shade and foster feelings of enclosure by creating intimate, small-scale public spaces with a varied and stimulating design.

In our study, building density, as the most popular indicator for density in urban planning, seems to have less effect on perceived heat stress and crowding in public than traffic, or people density. Tall buildings and narrow streets can increase daytime thermal comfort by providing shaded walkways while motorised but also stationary traffic exacerbates heat stress and crowding. Though limited solar access on the streetscape is beneficial during summertime, it increases thermal discomfort during the cold season. Moreover, less compact structures are beneficial for ventilation and nocturnal cooling, as open spaces foster out-going long-wave radiation and turbulent heat exchange (Onomura et al., 2016). This means that decoupling different forms of density can be a highly effective lever to reduce both crowding and heat stress. Where building density is high, we therefore recommend making traffic reduction and walkability a central concern for improvement. The importance of the general attractiveness and appreciation of a place for thermal comfort perception is also highlighted by other research (Lemonsu et al., 2019). Creating space for street trees, e.g., at the expense of parking space, enhances the quality of stay and decreases heat stress and crowding. Deciduous trees are advantageous since they provide shade in the summertime and solar access in winter. In narrow streets, where planting of trees might be impossible and would block ventilation, we, therefore, recommend using visual green elements at eye level (e.g., green facades, shrubs, or planters) to increase the "naturalness" of stressful urban settings, since our results showed positive psychological benefits achieved by urban greenery.

Wherever possible, places to rest combined with vegetation and (natural) shade should be made available, especially for residents with reduced mobility. If greened and made accessible, backyards and roofs bear great potential as high-quality (semi-)public spaces in high-density settings. Our findings support the idea that, in contrast to qualitative factors, building heights "play a relatively small role explaining perceived urban

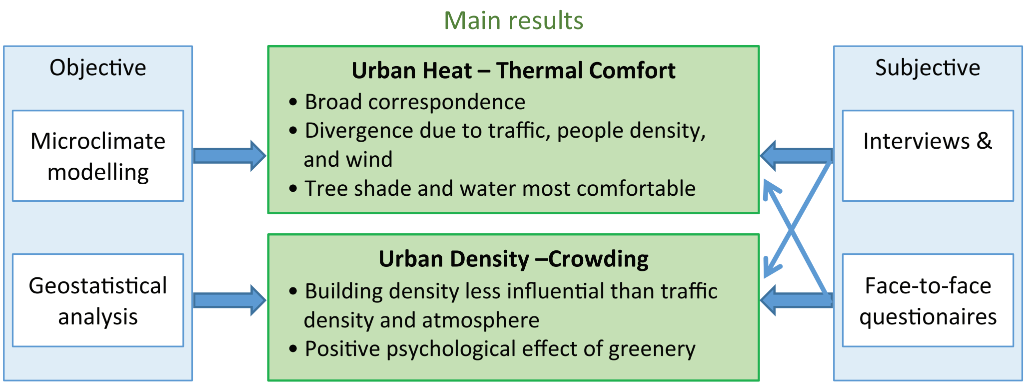

Figure 7. Summary of interaction and main results of the mixed-methods study.

stress" (Knöll et al., 2018, p. 805), while views into the distance are highly valued characteristics, especially among residents of dense neighbourhoods. This suggests that re-densification projects which combine additional storeys with a corresponding redesign of roof areas could result in added value for residents and increased acceptance. As we have seen, urban vegetation is crucial for reducing perceived heat stress, with tall trees providing the most substantial cooling effect. However, the full potential of parks or tree-covered squares for individual heat stress adaptation depends on their accessibility and attractiveness and can only be exploited if set in the right context. Studies by Kyttä et al. (2013) or Klemm et al. (2015) equally highlight that the quality of green space is more important than the quantity. Suburban residents seem to be more selective concerning their use of public space and do not seek peace and quiet to the same degree as residents of dense and highly stimulating neighbourhoods. Also, younger people and people with different cultural backgrounds tend to be more tolerant towards urban density and sensory overload than older citizens. Thus, public parks fulfil different functions in low- and high-density settings, also depending on the amount of private (green) space available and have to be designed bearing in mind the respective requirements of their residents.

In conclusion, our study has shown that the assessment of density parameters and thermal layout does not provide enough information to adequately balance conflicting objectives concerning the use of public urban space. The assessment has to be supplemented by local knowledge to determine the value of these spaces for residents and, thus, their meaning for the ecological and social resilience of cities and their inhabitants (Frerichs & Küpper, 2017). Effective, context-specific, user-centred design of green spaces can increase social and health benefits of UGI in neighbourhoods with different densities.

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Conflict of Interests

The authors declare no conflict of interests.

Supplementary Material

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

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Article

Economic Assessment of South African Urban Green Spaces Using the Proximity Principle: Municipal Valuation vs. Market Value

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Abstract
Urban green spaces (UGSs) deliver ecosystem services and potential economic benefits like increases in proximate residential property prices. The proximity principle (PP) premises that property prices increase as distance to UGS decreases. The PP has generally been confirmed by studies using municipal valuations and market values internationally. Conversely, South African studies have mostly employed municipal valuations and results have rejected the PP. There is an accepted interrelationship, but also often discrepancies, between municipal valuations and market values, presenting scope for this article to explore whether negative results are confirmed when market values replace municipal valuations in PP studies in the South African context. Accordingly, a statistical analysis of market values is completed in the Potchefstroom case study, where five test sites are replicated from studies that employed municipal valuations for longitudinal comparison. Results verify generally higher market values than municipal valuations and confirm the PP in two, but reject the PP in three, of five test sites. Previous studies employing municipal valuations in the case study confirmed the PP in one instance, thus presenting certain, but limited, inconsistencies between findings based on municipal valuation vs. market value. Results suggest that the market's willingness to pay for UGS proximity is sensitive to the ecosystem services and disservices rendered by specific UGS, but not significantly more than reflected in municipal valuations. Overall, findings underscore the need to protect and curate features that encourage willingness to pay for UGS proximity to increase municipal valuations and property taxes to help finance urban greening.

Keywords
green infrastructure; market value; municipal valuation; proximity principle; South Africa; urban green space

Issue
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1. Introduction

Urban green spaces (UGSs) include land parcels of various types located within the urban boundary, covered by permeable surfaces, soil, or flora (Girma et al., 2019, p. 138). Zoning classifications include residential, recreational, commercial, or agricultural categories to accommodate land uses like communal parks, playgrounds, sport facilities, greenways, green walls and roofs, urban forests, private gardens, wetlands and riparian areas, and street-side vegetation. UGSs may also encompass informal, residual, or unattended parcels, including derelict properties, vacant lots, and spaces along transportation corridors (J. Cilliers, 2013, p. 100; Girma et al., 2019, p. 138). Scholarly interest in UGSs has peaked in recent years, recognising their potential contributions to urban quality of life and service delivery as components of green infrastructure (du Toit et al., 2018, p. 249), defined as "the connected network of multifunctional, predominantly unbuilt, spaces that support both ecological and social activities and processes" (Venter et al., 2020, p. 2) to deliver benefits as ecosystem services.

Although academic support for the prioritisation of UGS planning and development is mounting, in practice these spaces are frequently side-lined as a result of the pressures caused by rapid urbanisation and associated land use change and conflict (Garcia-Garcia et al., 2020, p. 1). In South Africa, UGSs are often outcompeted by land uses deemed more deserving in terms of basic needs, political cachet, or economic potential (Afriyanie et al., 2020, p. 2). Accordingly, natural landscapes and existing UGSs undergo land use conversion, often following official densification strategies or informal land grabs by the destitute (Girma et al., 2019, p. 140; Lategan & Cilliers, 2016a, p. 15). South Africa's UGSs are particularly vulnerable, considering the country's growing housing backlog and a burgeoning population accommodated in the informal sector (Lategan et al., 2020, p. 2). This is exacerbated in a context where basic service delivery is declining and UGSs are considered luxuries and not necessities by many decision-makers (Girma et al., 2019, p. 139), even as residents in the Global South may generally depend significantly on certain provisioning and regulating ecosystem services provided by UGSs (see Section 2; Balbi et al., 2019, p. 5; Shackleton, 2021, pp. 217–219). Existing UGSs face additional challenges from inadequate institutional commitment and financial and human capital resources (Chishaleshale et al., 2015, p. 822). Government officials and planning practitioners in South Africa, and beyond, often present limited knowledge regarding green infrastructure and potential UGS contributions (Jacobs, 2019; Van Zyl, 2021). Countless UGSs are furthermore plagued by illegal dumping, pollution, crime, and invasive species that threaten indigenous biodiversity (Lategan & Cilliers, 2016b, p. 5). To defend existing greenery and promote the development of more UGSs an argument for the social, environmental, and specifically economic benefits UGSs can deliver must be made. Economic valuation is not intended to commodify greenery and view it solely through a financial lens, but to clarify an important and often misunderstood component of the multiple values presented to inform more balanced decision-making (Boyer & Polasky, 2004, p. 746; Pascual et al., 2017, p. 9).

This article departs with a review of the ecosystem services and ecosystem disservices potentially delivered by UGSs, emphasising prospective economic contributions. The next sections discuss economic valuation methods, focussing on hedonic price analyses and the proximity principle (PP), which states that property prices will increase as distance to UGS decreases; review findings from relevant studies, showing that South African examples have rejected the PP and have utilised municipal valuations in their investigations; and detail the interrelationship between municipal valuations and market values. The discussion provides scope to explore whether the negative results identified are confirmed when market values replace municipal valuations in PP studies in the South African context. From there, the case study of Potchefstroom, South Africa and the methodology followed in testing the PP based on estimated market values there are explained, before delivering results that inform main conclusions and recommendations.

2. Urban Green Spaces as Part of Green Infrastructure: Ecosystem Services and Ecosystem Disservices

UGSs may constitute components of the links and nodes that comprise multifunctional green infrastructure networks (Pauleit et al., 2021) that accommodate urban ecosystems and provide various ecosystem services. These ecosystem services deliver several potential environmental, social, and economic benefits (Grafius et al., 2018, p. 558). Environmental and social benefits are frequently more obvious (Van Oijstaeijen et al., 2020, p. 1) than economic benefits given the complexity of calculating and articulating such values (E. J. Cilliers & Timmermans, 2013). Identifying economic contributions is vital towards greener planning agendas as decision-makers require evidence of such offerings to mainstream green infrastructure at strategic management level (Van Oijstaeijen et al., 2020, p. 2), to capitalise on the full range of benefits presented and to address the disadvantages, or ecosystem disservices, potentially rendered. The ecosystem disservices concept recognises that the same ecosystem functions that provide social, environmental, and economic benefits, may render contrasting negative impacts (Davoren & Shackleton, 2021). Table 1 summarises the ecosystem services and ecosystem disservices concepts.

Many of these ecosystem disservices are prevalent in South Africa, deterring users from accessing facilities and influencing willingness to buy properties in proximity to UGSs (Gómez-Baggethun & Barton, 2013, p. 238). UGSs are potential hotspots for criminal activity, especially when lushly vegetated, poorly lit, and unmaintained, as is often the case in South Africa (Lategan & Cilliers, 2016b, P. 9). Such disservices and the others noted above, in conjunction with the restorative power and aesthetic appeal of green views, result in many property owners preferring green vistas (Panduro & Veie, 2013, p. 126; Sharmin, 2020, p. 100) and not immediate proximity. Several economic valuation methods of UGSs attempt to account for the complex relationship of push and pull factors that may underpin a cost-benefit analysis of such land uses.

3. Economic Valuation Methodologies and the Proximity Principle

Influential economic valuation approaches include the market price method, the replacement/substitute method, contingent valuation, the contingent choice method, benefit transfer, and hedonic pricing (Cilliers

Table 1. Summary of UGS ecosystem services and disservices.

Categories	Examples of Ecosystem Services	Examples of Ecosystem Disservices
Provisioning	Protection and restoration of natural resources delivering water, food, medicine, firewood and material for construction, arts, and crafts.	Invasive species outcompete indigenous species; altered species interactions and populations; reduced air quality from production of volatile organic compounds by plants; urban trees may decrease access to sunlight; keeping of livestock in urban areas damages plants and creates unhygienic conditions; infrastructure damage (e.g., tree roots that damage roads and kerbs and block drains and water pipes); maintenance costs for green infrastructure components and surrounding buildings; catastrophic effects of natural disasters such as floods. Security concerns (shelter for criminals, obscured views); negative emotions such as discomfort, anxiety, or fear towards urban animals and plants; negative health impacts (allergic reactions); increased noise (e.g., bird and frog calls); aesthetic impacts (e.g., wild spontaneous vegetation [weeds]); unpleasant exposure to the elements (e.g., excessive winds); safety hazards (e.g., tree falls); poisonous plants; pests and diseases (Potential negative impact on property values).
Regulating	Improved air and water quality; regulating urban temperature (reducing the urban heat island effect); carbon sequestration; waste water treatment; soil erosion control; moderation of extreme events (e.g., flooding); pollination; biological control; replacing expensive conventional and technical environmental management systems (e.g., storm water management, water retention, microclimate regulation).	
Supporting	Enhancing urban biodiversity (urban habitats); conserving natural ecosystems.	
Cultural	Improving mental and physical health; aesthetic contributions; recreation and eco-tourism; encouraging social cohesion; reinforcing cultural heritage and values; spiritual enrichment; strengthening sense of place; increase in city liveability and marketability (Potential increase in property value and reciprocal increase in property tax returns).	

Sources: Own construction from Cilliers and Cilliers (2015, p. 15); S. Cilliers et al. (2013, p. 5); Davoren and Shackleton (2021); du Toit et al. (2018); Grafius et al. (2018, p. 558); Steenkamp et al. (2021).

& Cilliers, 2015, p. 3). Hedonic price analysis is highlighted for its broad application internationally and in South Africa. Hedonic price analysis considers that residential properties are not homogeneous, but reflect discrete attributions that influence property value that are each studied individually (Daams et al., 2019, p. 389). A prominent example includes proximity to UGS, encapsulated in the PP (Cilliers & Cilliers, 2015, p. 5), revealing the market's willingness to pay for access to such spaces. Examples of studies are captured in Table 2.

Table 2 demonstrates that the PP has delivered fairly consistent results, depending on the parameters employed and study area identified. The majority of studies have confirmed the PP using market values and not municipal valuations, with the exception of studies based in South Africa.

4. Municipal Valuation vs. Market Value

Municipal valuation refers to a value placed on a property by assessors for local authorities as the basis for property taxation as a source of municipal revenue (Cypher & Hansz, 2003, p. 305; Janssen & Söderberg, 1999, p. 359). Municipal valuation is bound by set regulations to ensure just outcomes (Ramakhula, 2010, p. 22). In South Africa, the Local Government Municipal Property Rates Act of 2004 regulates local government property taxation and allows for comparative analysis and computer aided mass appraisals (Nyabwengi, 2020, p. 1736). In South Africa, statutory requirements prescribe that municipal values should equal market values, but Ghyoot (2008) observed that valuers often allow for municipal valuations within a 10% divergence of market values.

Market value refers to the price a property demands in the open market (Malaitham et al., 2020, p. 154), reflecting demand and supply (Das & Thappa, 2018, p. 15). A property's market value depends on several variables (Das & Thappa, 2018, p. 16; Janssen & Söderberg, 1999, p. 359), appraised by a real estate agent or other professionals when properties are put up for sale (Janssen & Söderberg, 1999, p. 359). Unlike with municipal valuation, the determination of market value may not be bound by regulations but may follow standard approaches such as direct capital comparison, income capitalisation, the cost approach, and residual or developers approach (Das & Thappa, 2018). Municipal assessors consider the market and professionals and estate agents may use municipal valuations as components in their assessments (Janssen & Söderberg, 1999, p. 360). Although determination processes for municipal valuations and market values may differ, they present a complex interrelationship in their shared objective to determine property value (Cypher & Hansz, 2003, pp. 305–306).

Table 2. Selected studies employing the PP.

Authors	Case Study	Municipal Valuation/ Market Value	Proximity Principle
Bolitzer and Netusil (2000)	Portland, Oregon, USA	Market value	Confirmed
Kim and Johnson (2002)	Corvallis, Oregon, USA	Market value	Confirmed
Morancho (2003)	Spain	Market value	Confirmed
Tajima (2003)	Boston, Massachusetts, USA	Market value	Confirmed
Boyer and Polasky (2004)	Multiple	Market value	Confirmed
Crompton (2005)	Multiple	Market value	Confirmed
v Anderson and West (2006)	Minneapolis—St Paul Metro, Minnesota, USA	Market value	Confirmed
Dehring and Dunse (2006)	Aberdeen, Scotland	Market value	Confirmed
Kong et al. (2007)	Jinan City, China	Market value	Confirmed
Conway et al. (2010)	Los Angeles, California, USA	Market value	Confirmed
Payton et al. (2008)	Indianapolis/Marion County, Indiana, USA	Market value	Confirmed
Arvanitidis et al. (2009)	Several European Cities	Not specified	Confirmed
Chen and Jim (2010)	Shenzhen, China	Market values	Confirmed
Biao et al. (2012)	Beijing, China	Market value	Confirmed
Kovacs (2012)	Portland, Oregon, USA	Market value	Confirmed
J. Cilliers (2013)	Potchefstroom, South Africa	Municipal valuation	Rejected
Konijnendijk et al. (2013)	Multiple	Market value	Confirmed
Panduro and Veie (2013)	Aalborg, Denmark	Market value	Confirmed
Gibbons et al. (2014)	England	Market value	Confirmed
Cilliers and Cilliers (2015)	Potchefstroom, South Africa	Municipal valuation	Rejected
Wen et al. (2015)	Hangzhou, China	Market value	Confirmed
Loret de Mola et al. (2017)	Bogotá, Colombia; Buenos Aires, Argentina; Lima, Peru; Mexico City, Mexico; and Santiago, Chile	Market value (real estate data at district level)	Confirmed
Chen and Li (2018)	Guangzhou, China	Market value	Confirmed
Immergluck and Balan (2018)	Atlanta, Georgia, USA	Market value	Confirmed
Daams et al. (2019)	Amsterdam, the Netherlands	Market value	Confirmed
Czembrowski et al. (2019)	Stockholm, Sweden	Market value	Confirmed
Combrinck et al. (2020)	Potchefstroom, South Africa	Municipal valuation	Rejected
Sharmin (2020)	Dhaka, Bangladesh	Market value	Confirmed
Samad et al. (2020)	Kuala Lumpur, Malaysia	Market value	Confirmed
Yu et al. (2020)	Shenzhen, China	Rental market value	Confirmed

It is widely recognised that valuations and actual market values rarely coincide (Babawale, 2013, p. 387). Various cases of municipal valuations being both lower and higher than estimated market values, or reaslised sales prices, have been reported (Ghyoot, 2008; Ntuli, 2019; Sokutu, 2021). In cases of the latter, allowing for processes of appeal, but in cases of the first, rarely resulting in objections due to lower property taxes due by owners. The question is not necessarily if there is a difference, but rather to what extent the difference between municipal valuations and market values are manifested. In line with the focus of this article, Malaitham et al. (2020, p. 154) suggest that there is uncertainty regarding the impact of municipal valuation vs. market value in studies on the PP and UGS, as limited studies have been conducted to compare findings using both as variables. The following section elaborates on the choice of case study for this research and discusses the methodology employed to address the issues raised in the literature review.

5. Case Study and Methodology

Potchefstroom, South Africa (26°42’53’’S, 27°05’49’’E) was selected as case study based on the previous studies completed there by Cilliers and Cilliers (2015) and

Combrinck et al. (2020; see Table 2) who investigated the PP by examining sites in five upper middle- to high-income neighbourhoods where a central public UGS and surrounding detached dwellings provided a research sample. Sample areas were categorised within socio-economic status levels of four and five, thus presenting shared characteristics in accordance with middle- to high-income earners in terms of employment status, household size, number of rooms occupied, access to basic services, and schooling status (Lubbe et al., 2010, p. 2903). Owing to this status, UGSs in the sample were fairly well-maintained as a result of both public and private ownership and management and presented significant plant diversity and species richness compared to those in lower income areas (Lubbe, 2011, p. 37). In keeping with Combrinck et al. (2020), test sites included UGSs and surrounding properties in Grimbeek Park, bordering a golf course and areas used for birdwatching and horseback riding; van der Hoff Park, bordering an equestrian open space and wetlands with high biodiversity; Heilige Akker, bordering the sporting grounds of a local university and presenting limited vegetation and tree cover; Oewersig, with dense vegetation bordering the Mooi River and surrounding open space; and next to the Potchefstroom Dam with dense vegetation and tree cover (Cilliers & Cilliers, 2015; Combrinck et al., 2020). Properties within each sample area were divided into three zones depending on distance to an UGS. Properties in Zone 1 were situated directly adjacent to an UGS; those in Zone 2 were further away, mostly across the street from those in Zone 1; and Zone 3 properties were further away from the UGS, mostly located in the same block, or one street away from those in Zone 2. All properties included ranged between 1,000 m^2 to 2,000 m^2 in size, with a limited number presenting sizes below or above these parameters. Sample properties were furthermore endowed with ample private UGS, in keeping with expectations for detached properties at this socio-economic status level. Despite international evidence to the contrary (Dehring & Dunse, 2006, p. 565), Lategan and Cilliers (2016b) found that in South Africa, the availability of private UGS did not necessarily compensate for public UGS as private UGSs cannot fulfil the multiple functions of public spaces, specifically related to cultural ecosystem services, as part of local heritage and neighbourhood identity, as venues of communal gathering and social interaction or in terms of amenities provided. Several studies have commented on the impacts of location, density, UGS type, size, and quality as well as the availability of private UGS on proximate property values in relation to public UGSs (e.g., Anderson & West, 2006; Konijnendijk et al., 2013; Sharmin, 2020), with the majority generally confirming the PP internationally (see Table 2).

This research is primarily interested in the degree to which public UGSs are valued in South Africa in fairly homogenous neighbourhoods and if and how such trends fluctuate when employing estimated market values vs. municipal valuations. Combrinck et al. (2020) employed average price per square metre in South African Rand for each property in the sample derived from 2019 municipal valuations. This article compared these values to estimated market values for the same properties gathered in 2020. Market values were obtained from a reputable international real estate agency's Potchefstroom branch who based its market valuations on four sources. Firstly, "Revolution" software that triangulates inputs by agents from the last 15 years and makes a comparison based on property characteristics. Secondly, "Lightstone" software, which collaborates with South Africa's deeds offices and provides a mean property price compared to others of approximately the same size in the area. Thirdly, the latest municipal valuation role was consulted as part of standard practice. Lastly, the agency drew on the professional discretion of its agents as property experts.

Descriptive statistics were used to report municipal valuations for each property per square metre and compare these values with 2019 municipal valuations. A dependent t-test compared 2019 municipal valuations and 2020 market value estimates. This was followed by analysis of variance (ANOVA) and Kruskal–Wallis tests to determine whether a practically significant difference existed between the delineated zones. Where results differed, the non-parametric test (Kruskal-Wallis) was preferred. This research replicates the methodologies employed by Cilliers and Cilliers (2015) and Combrinck et al. (2020) in recognition of their scientific contributions and for the purpose of direct longitudinal comparison. This article should thus not be regarded as a critique of previous studies, Combrinck et al. (2020) in particular, but as an attempt to expand existing knowledge and deepen understanding of the South African exceptionalism exhibited in Table 2.

6. Results

The 2019 municipal valuations observed were 28% lower than 2020 market value estimates. This represents a considerable difference from standard deviation guidelines, often set at between 5% and 10% (Babawale, 2013, p. 396; Hager & Lord, 1985). For contextualisation, when further compared to a general increase of 14,73% identified in average residential sale prices realised for detached properties in Potchefstroom during the same period (2019 to 2020) (Property24, 2021), findings thus represent a disproportional and significant difference. Table 3 captures these values and summarises the outcome of the dependent t-test. An effect size of ≈ 0.2 indicates a small, no practically significant difference; an effect size of ≈ 0.5 indicates a medium, practically significant difference; and an effect size of ≈ 0.8 indicates a large, practically significant difference.

Results indicate an overall large practically significant difference (≈ 0.8) between municipal valuations and market value estimates. Market value estimates were

Table 3. Dependent t-test results.

Area	Zone	N (188)	Municipal Valuation in South African Rand/m^2	Market Value in South African Rand/m^2	Municipal Standard Deviation	Market Standard Deviation	Effect Size	T-test
							a ≈ 0,2 small b ≈ 0,5 medium c ≈ 0,8 large	Statistically significant difference between municipal and market (p < 0,05)
Grimbeek Park	1	14	1,260.7	1,252.91	237.61	375.85	0,02a	0,941
	2	14	1,611.67	1,584.32	295.96	421.64	0,06b	0,668
	3	13	1,699.25	1,493.18	269.72	208.74	0,76c	0,019
van der Hoff Park	1	15	1,290.59	1,683.48	341.15	753.19	0,52b	0,016
	2	15	1,472.43	1,579.05	237.86	224.65	0,45b	0,143
	3	13	1,624.3	1,902.34	279	339.58	0,82c	0
Heilige Akker	1	10	1,751.96	2,299.21	353.01	631.25	0,87c	0,012
	2	12	1,904.15	2,692.38	280.09	858.19	0,92c	0,005
	3	14	1,850.28	1,930.69	757.54	356.16	0,19a	0,603
Oewersig	1	14	1,668.44	2,355.76	338.6	642.54	1,07c	0
	2	14	1,852.15	2,480.35	360.64	876.91	0,72c	0,031
	3	13	1,549.2	2,037.73	415.18	255.85	1,52c	0
Potchefstroom Dam	1	9	1,116.44	2,139.69	336.36	1,213.69	0,84c	0,019
	2	9	1,303.45	2,223.11	421.46	408.47	2,25c	0,001
	3	9	1,448.64	2,308.59	421.61	1,009.9	0,85c	0

significantly higher than municipal valuations in four of five test sites, with the exception of Grimbeek Park. Figure 1 illustrates the differences captured in Table 3 regarding fluctuations from Zone 1 to Zone 3 in each test site.

In Grimbeek Park, results presented a general rejection of the PP from Zone 1 to 3, but confirmed the principle between Zones 2 and 3 with regard to estimated market values. Findings differed slightly in that municipal valuations showed a consistent upward trajectory to reject the PP from Zone 1 to 3. In van der Hoff Park, the PP was confirmed between Zone 1 and Zone 2, but rejected between Zones 1 and 3. Thus, differing slightly from municipal valuation findings that showed a consistent upward trajectory, but confirming findings on a rejection of the PP in general terms. In Heilige Akker, the PP was rejected between Zone 1 and Zone 2, but confirmed for Zone 1 to Zone 3. Findings concurred with data from municipal valuations showing a peak in Zone 2, but departed where the PP was rejected. For Oewersig, data rejected the PP between Zone 1 and Zone 2, but confirmed the principle for Zone 1 to Zone 3. Results were mirrored in municipal valuations. For Potchefstroom Dam, Zone 3 presented a higher market value estimate than Zone 2 and Zone 1, resulting in a rejection of the PP. This trend echoed findings derived from municipal valuations.

Statistical substantiation to the findings above were provided via ANOVA and Kruskal-Wallis testing using 2020 market value estimates. For ANOVA an effect size of ≈ 0.2 indicates a small, no practically significant difference; an effect size of ≈ 0.5 indicates a medium, practically visible difference; and an effect size of ≈ 0.8 indicates a large, practically significant difference. For the Kruskal-Wallis test, an effect size of ≈ 0.1 indicates a small or no practically significant difference; an effect size of ≈ 0.3 indicates a medium or practically visible difference; and an effect size of ≈ 0.5 indicates a large or practically significant difference. Results are captured in Table 4.

The results from the Kruskal-Wallis test were preferred when the outcomes of statistical tests differed. This is also reflected in Table 5 that summarises complete results in conjunction with Combrinck et al.'s (2020) main findings.

7. Conclusions

Municipal valuations were considerably lower than estimated market values in almost all test sites and a large practically significant difference could be established; in general, by a significant 28%, which is well above accepted standards of deviation. Grimbeek Park presented an interesting case, as the only example in which municipal valuations exceeded estimated market values. It falls beyond the scope of this article to investigate the reasons behind this and opportunities for further research are thus presented. As a point of departure for future investigations, it is interesting to note that in a review of the five test sites included in this research,

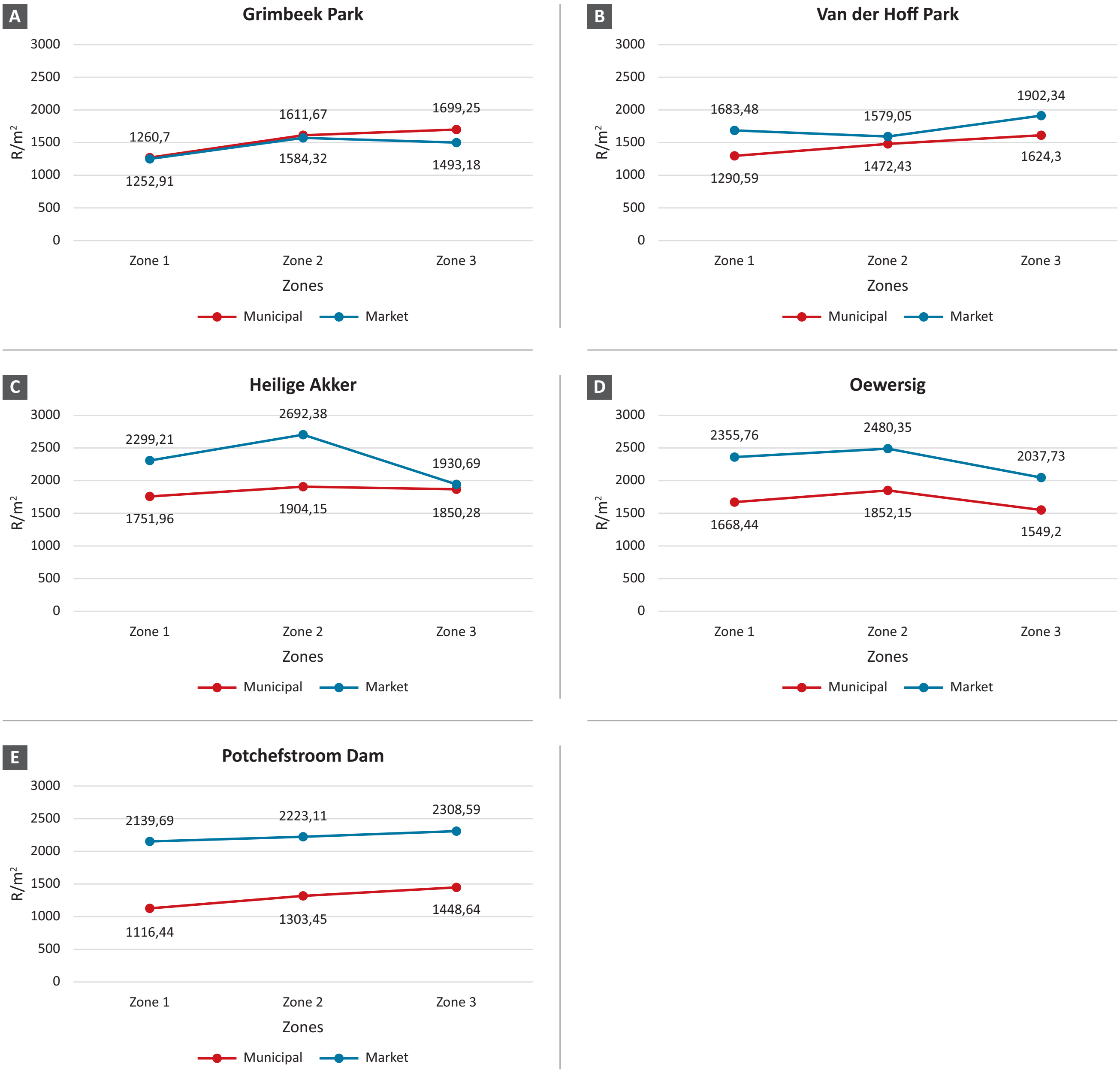

Figure 1. Mean South African Rand/m^2 municipal valuation and estimated market values for the Potchefstroom sample.

based on attributes related to UGSs and the environmental, social, and economic benefits (as ecosystem services) offered, Combrinck (2020) found that Grimbeek Park's UGS delivered the highest overall scores. As a supplementary consideration, the UGS in Grimbeek Park presented the only example of a golf course. Several international studies have indicated that golf courses specifically increase proximate property values at significant levels (Crompton & Nicholls, 2020; Nicholls & Crompton, 2007; Yates & Cowart, 2019).

Another interesting observation relates to the zone in which values reached a peak in each test site. Using municipal valuations, Combrinck et al. (2020) established peaks in Zone 1 in no test sites; peaks in Zone 2 in two test sites (Heilige Akker and Oewersig); and peaks in Zone 3 in three test sites (Grimbeek Park, van der Hoff Park, and Potchefstroom Dam). In contrast, estimated market values delivered peaks in Zone 1 for no test sites (yet, in van der Hoff Park Zone 1 presented a higher estimate than Zone 2); peaks in Zone 2 for three test sites (Grimbeek Park, Heilige Akker, and Oewersig); and peaks in Zone 3 for two test sites (van der Hoff Park and Potchefstroom Dam). Peaks were thus registered significantly differently using municipal valuation vs. estimated market value.

The absence of peaks in Zone 1 in both data sets, even where the PP was confirmed (Heilige Akker and Oewersig) underscores the negative impacts of adjacency to UGS in South Africa, ascribed to ecosystem disservices such as crime, a lack of maintenance, and other nuisance factors (see Davoren & Shackleton, 2021, and Table 1). The presence of a higher market value

Table 4. ANOVA and Kruskal-Wallis testing.

Area	Zone	N (188)	Market Value in South African Rand/m^2	Standard Deviation	Effect Size				ANOVA	Kruskal-Wallis
					ANOVA a ≈ 0,2 small b ≈ 0,5 medium c ≈ 0,8 large		Kruskal-Wallis a ≈ 0,1 small b ≈ 0,3 medium c ≈ 0,5 large		Statistically significant difference between means (p < 0,05)	Statistically significant difference between mean ranks (p < 0,05)
					1 with…	2 with…	1 with…	2 with…		
Grimbeek Park	1	14	1,252.91	375.85						
	2	14	1,584.32	421.64	0.79c		0,373b		0,047	0,057
	3	13	1,493.18	208.74	0.64b	0.22a	0,411b	0,028a		
van der Hoff Park	1	15	1,683.48	753.19						
	2	15	1,579.05	224.65	0,14a		0,140a		0,237	0,022
	3	13	1,902.34	339.58	0,29a	0,95c	0,440c	0,457c		
Heilige Akker	1	10	2,299.21	631.25						
	2	12	2,692.38	858.19	0,46b		0,197a		0,017	0,011
	3	14	1,930.69	356.16	0,58b	0,89c	0,287b	0,615c		
Oewersig	1	14	2,355.76	642.54						
	2	14	2,480.35	876.91	0,14a		0,052a		0,208	0,35
	3	13	2,037.73	255.85	0,49b	0,50b	0,224a	0,252b		
Potchefstroom Dam	1	9	2,139.69	1,213.69						
	2	9	2,223.11	408.47	0,07a		0,468c		0,93	0,203
	3	9	2,308.59	1,009.9	0,14a	0,08a	0,177a	0,135a		

estimate in Zone 1 than Zone 2 in van der Hoff Park and more peaks in Zone 2 than Zone 3, when contemplating estimated market value vs. municipal valuation, indicate that whilst immediate adjacency is not always valued, some proximity to UGSs may be appreciated to capitalise on ecosystem services (see Escobedo, 2021, p. 227, and Table 1) and reduce the potential impacts of ecosystem disservices, despite the presence of domestic UGSs. This may also relate to the impacts of visual access to public greenery that present pleasant vistas or offer amenities (Panduro & Veie, 2013, p. 126; Sharmin, 2020). Although the aim of this study was not to determine to what extent the market's willingness to pay is sensitive to the ecosystem services and ecosystem disservices produced by specific UGSs, the importance of acknowledging these aspects is emphasised in the literature (Davoren & Shackleton, 2021).

The results in Figure 1, together with the average medium practically significant differences established from zone to zone, confirmed the PP in two test sites using estimated market values compared to one when employing municipal valuations. These are not overwhelming contrasts, but preliminary findings indicate that the relationship between UGS proximity and willingness to pay for proximity may be less clear-cut and linear in South Africa than previously reported based on municipal valuations (Cilliers & Cilliers, 2015; Combrinck et al., 2020). Results still contrast with international norms on the general confirmation of the PP using estimated market values as variables. These preliminary findings suggest that the influence of the variable employed (municipal valuation vs. market value) can thus potentially be disregarded as an explanation for exceptions identified in previous South African-based research on the PP (Table 2).

Although efforts to quantify the value of UGSs have increased, more research is needed in the Global South to provide case studies to guide context-based planning (S. S. Cilliers et al., 2021) and clarify the relationship between UGS proximity and willingness to pay. Future studies may compare municipal valuations and market value estimates on a larger scale in various sites and may consider the physical attributes and specific ecosystem services and ecosystem disservices rendered by individual UGSs through more qualitative approaches to address certain limitations of this research. The complexity of developing integrated urban planning and management systems focusing on ecosystem services and

Table 5. Comparative summary of results.

		Municipal Valuation (2019)						Estimated Market Value (2020)					
Test Site	Estimated market value higher than municipal valuation	Zone 1 vs. Zone 2	Zone 2 vs. Zone 3	Zone 1 vs. Zone 3	PP from zone to zone	General effect size (non-parametric test)	Verdict PP based on municipal valuation	Zone 1 vs. Zone 2	Zone 2 vs. Zone 3	Zone 1 vs. Zone 3	PP from zone to zone	General effect size (non-parametric test)	Verdict PP (estimated market value)
Grimbeek Park	No	Lower	Lower	Lower (Zone 3 peak)	Rejected (Zone 1 to 3)	Large	**Rejected**	Lower	Higher (Zone 2 peak)	Lower	Confirmed (Zone 2 to 3) Rejected (Zone 1 to 3)	Medium	**Rejected**
van der Hoff Park	Yes	Lower	Lower	Lower (Zone 3 peak)	Rejected (Zone 1 to 3)	Medium	**Rejected**	Higher	Lower	Lower (Zone 3 peak)	Confirmed (Zone 1 to 2) Rejected (Zone 1 to 3)	Medium	**Rejected**
Heilige Akker	Yes	Lower	Higher (Zone 2 peak)	Lower	Rejected (Zone 1 to 3)	Small	**Rejected**	Lower	Higher (Zone 2 peak)	Higher	Rejected (Zone 1 to 2) Confirmed (Zone 1 to 3)	Medium	**Confirmed**
Oewersig	Yes	Lower	Higher (Zone 2 peak)	Higher	Confirmed (Zone 1 to 3)	Medium	**Confirmed**	Lower	Higher (Zone 2 peak)	Higher	Rejected (Zone 1 to 2) Confirmed (Zone 1 to 3)	Small	**Confirmed**
Potchefstroom Dam	Yes	Lower	Lower	Lower (Zone 3 peak)	Rejected (Zone 1 to 3)	Medium	**Rejected**	Lower	Lower	Lower (Zone 3 peak)	Rejected (Zone 1 to 3)	Medium	**Rejected**

ecosystem disservices, needs to be recognised, as one element in urban ecosystems may produce both ecosystem services and ecosystem disservices that may be perceived and valued according to individual interpretations and preferences (Blanco et al., 2019, p. 3). In line with this, it is pertinent to recognise the plurality of values assigned to nature and the influence of variables such as worldviews and power dynamics in the translation of the values identified to decision-makers and stakeholders (Pascual et al., 2017, p. 14). Davoren and Shackleton (2021) further reported a dearth of research on ecosystem disservices, especially in the Global South, and emphasised the importance of mapping the distribution of those ecosystem disservices that influence human health and well-being, in the same way as ecosystem services have been mapped (e.g., Plieninger et al., 2013).

Further refinement and substantiation of the findings presented in this article should incentivise local authorities, specifically in South Africa with its contrasting results, to invest in UGSs to curate features that encourage willingness to pay for UGS proximity and address those ecosystem disservices that deter property buyers from paying more to augment revenue from property taxes. Such proceeds should be reinvested in UGSs as green infrastructure to further capitalise on valuable green assets that may deliver indispensable services and potential economic returns.

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Conflict of Interests

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Article

Close-To-Nature Heuristic Design Principles for Future Urban Green Infrastructure

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Abstract
The global nature-climate crisis along with a fundamental shift in world population towards cities and towns has sharpened the focus on the role of urban green infrastructure. Green infrastructure has the potential to deliver cost-effective, nature-based solutions to help mitigate problems of climate change as well as provide improved human well-being through the ecosystem services inherent in landscapes rich in biodiversity. The absence of under-pinning science, specifically complex systems science and ecosystem theory in the design and planning of urban green infrastructure, has limited the capacity of these landscapes to deliver ecosystem services and to effectively demonstrate natural resilience to the impacts of climate change. To meet future challenges of environmental uncertainty and social change, the design of urban green space should embrace an adaptive ecosystem-based approach that includes fully integrated participatory planning and implementation strategies founded on principles of close to nature science. Our article offers two models to inform green space planning: urban green space framework and sustainable urban community network. Both concepts provide the foundation for six ecosystem-based design principles. In a case study on Essex green infrastructure, UK, recommendations made by the Essex Climate Action Commission to transform land management practices are presented as examples of adopting principles of the ecosystem approach and nature-based science. Our article concludes by emphasising the importance of reconnecting society with nature in cities through close-to-nature design of urban green space to secure essential ecosystem services and to build resilience to the impacts of climate change.

Keywords
ecosystem-based approach; Essex Climate Action Plan; nature-based solutions; sustainable urban community network; urban green infrastructure; urban green space framework

Issue
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1. Introduction

The state of the planet and the emerging impacts of climate change and biodiversity loss are in the top five global risks by "likelihood" and "impact" according to the latest Global Risks Perception Surveys (see World Economic Forum, 2019, 2020, 2021). Failure of effective socio-environmental policy coupled with increasing human development and commercial prosperity have come at a considerable cost to biodiversity as the stock of natural capital per person has declined by nearly 40%, and extinction rates are estimated to be 100 to 1,000 times higher than the baseline rate (Dasgupta, 2021). Environmental trends broadly correspond with human demographic changes including a profound shift across the world towards urbanisation (Department of Economic and Social Affairs, 2018).

Across Europe, 74% of people are living in towns and cities that have had to adapt to rapid development and overcrowding by the hasty construction of often poorly planned new build with inherent environmental problems (Artmann et al., 2017; Bertram & Rehdanz, 2015; Kabisch et al., 2016). Modern functional urban planning across the world operates to a "line and grid" system (Stanislawski, 1946), which includes calculating the proximity and size of open space to residential builds (Moseley et al., 2013; Natural England, 2010). Experts argue that such linear green island models ignore more complex site specific and social factors such as mobility and the distance people are prepared to travel from their homes to communal green spaces (Grahn & Stigsdotter, 2003; Moseley et al., 2013). There has been little scope for integrating much needed green infrastructure into existing urban build (Kasanko et al., 2006), with consequences for towns and cities that require adaptive capacity and resilience to cope with rapid environmental change, such as drought and floods (Koomen & Diogo, 2015).

A more comprehensive systematic analysis of urban open space and green infrastructure of the kind required in the assessment of ecosystem services is needed with a follow-up in appropriate adaptive management planning. In this article, we explore some of the apparent obstacles faced by urban designers and planners to working with an ecosystem services framework and propose mechanisms of knowledge transfer, using appropriate conceptual models such as regenerative design and ecosystem-based design as heuristic design principles, which are structured around theories of science. Using principles of complex systems, ecological thermodynamics, and ecosystem theory, a whole system approach to urban design and planning is advanced. The article presents a contemporary case study in Essex, UK, based on the recommendations set out by the Essex Climate Action (ECA) Commission to future-proof the living landscape against the impacts of rapid environmental change. It concludes with a call for more real-time information on the needs and demands of different user groups to overcome barriers, and also for specific improvements in user service networks.

2. Conventional Urban Design Practice

Since the launch of the ecosystem services assessment framework in 2005 (see Millennium Ecosystem Assessment, 2005), advances have been made in the development of ecosystem services cascade models (Hubacek & Kronenberg, 2013; Luederitz et al., 2015), but progress in accounting of services for urban green spaces lags behind studies on other ecosystems, particularly when it comes to promoting ecosystem function, structure, and network patterns (Haase et al., 2014). In part, this can be attributed to a lack of understanding within planning departments of the relationship between key ecological attributes (KEA), ecosystem function, and the cultural values attributed to urban green infrastructure (Artmann et al., 2017; Luederitz et al., 2015). Consequently, few green infrastructure plans demonstrate an ecosystem-based approach with clear links between ecological and social benefits (Daniel et al., 2012; Haase et al., 2014; Kremer et al., 2016). For many urban planners, the multiple use of urban spaces and the diversity of cultural services make it difficult to apply ecosystem-based models such as the Common International Classification of Ecosystem Services (Costanza et al., 2014; Haines-Young & Potschin, 2017; Kumar et al., 2014), and to deliver payment for ecosystem services (Reed et al., 2017; The Economics of Ecosystems and Biodiversity, 2010, 2011; URS, 2013).

The Economics of Ecosystems and Biodiversity, the European Environmental Bureau, and the Common International Classification of Ecosystem Services (Maes et al., 2014, 2016) are designed to assess natural capital and the preservation of ecological assets as well as safeguard ecosystem services at both regional and national scales. A similar certification scheme, the Sustainable Sites Initiative (SITES) makes explicit the importance of adhering to performance-based guidelines and tasks designers with setting specific goals for the conservation of services (Calkins, 2012; SITES, 2015). The practical guidelines presented in SITES consist mainly of quantitative measures of performance (Windhager et al., 2010) and focus on sustainable land design, but are not specifically intended to assess whole ecosystem function and services networks.

Many green planning models launched in recent years under the banner of "eco-urbanism" apply novel technical solutions to remedy environmental problems (Lennon et al., 2017). Examples include large scale river restoration programmes, sustainable urban drainage schemes (SUDS), and engineering projects such as green and blue space adaptation for urban areas and eco towns (Town and Country Planning Association London, 2015). However, many of these initiatives have yet to be developed into a fully integrated plan for eco-social infrastructure. More recently, the Directorate-General for Research and Innovation (2015) has adopted the concept of nature-based solutions to restore degraded ecosystems and promote improved derived services as well as making them adaptive to climate change (Cohen-Schacham et al., 2016; Nesshöver et al., 2017). The potential for nature-based solutions to increase urban resilience and improve social wellbeing is affirmed in the Commission's strategy for green infrastructure but is not complemented by appropriate theory-to-practice models and toolkits necessary for effective implementation (Bush & Doyon, 2019).

Published in 2014, the European Commission strategy for green spaces titled *Green Infrastructure—Enhancing Europe's Natural Capital* was launched with the objective of delivering a wide range of ecosystem services as part of spatial planning and urban development (European Commission, 2014). The strategy also aims to assess understanding and guidance for decision-makers and civil society on the principles and application of ecosystem-based approaches. The potential for integrating ecosystem-based approaches into urban planning is clear but is yet to be fully developed in both research and practice. Gaps remain in both understanding and experience in implementing urban planning processes that deliver wide-ranging ecological benefits as well as social value (Bush & Doyon, 2019).

3. Developing Conceptual Models for Sustainable Urban Green Infrastructure

Hierarchical network models are used extensively in business studies and ecosystem theory (see Jørgensen et al., 2015), but have yet to make headway in the world of design and planning. Part of the problem is the difficulties perceived by practitioners in translating an essentially scientific concept into a very technical design format (Luederitz et al., 2015). Conventional approaches used in the design of urban space are spatially represented in two-dimension cartographic form with the emphasis on location; relationship to other spaces and structures; and use of open space by the community for recreation. Until now, there has been little occasion for thinking more holistically about the functional role of urban green infrastructure and how this might influence location, juxtaposition with other features, scale, and connectivity across the urban landscape and beyond into the rural domain. Hierarchical and deeply interconnected representations of urban green infrastructure encourage practitioners to consider the use and design of space in three dimensions. For example, the fundamental geophysical elements of a landscape are linked to derived cultural values through a network of forms contributing to complex processes that make up the function of the ecosystem and provide the necessary services.

We propose two interrelated conceptual models as part of the ecosystem-based approach to urban design and planning, which are urban green space framework (UGSF) and sustainable urban community network (SUCN).

The UGSF model describes and characterises the physical nature and attributes of urban space using ecosystem theory and principles of complex systems. It adopts a meta-systemic approach using KEA (see Schick et al., 2019) as proxy indicators for ecosystem function. Six KEA of relevance to green infrastructure planning are presented below:

- Scale: The minimum dynamic area required for partial or all basic ecosystem functions and processes. It is determined by the ecological envelope of the (semi-)natural system;
- Hierarchy: It recognises that nature is assembled hierarchically. Permeations between scale breaks ensures flow of material and energy;
- Networks: Components of the ecosystem are interlinked. Change in status of a component will affect the whole system;
- Information: The capacity for an ecosystem to self-order and maintain function over time is contingent on the structural, genetic, and behavioural diversity within;
- Biomass: Productivity, longevity, adaptability, resilience, and resistance to change is dependent on "exergy"—useful material and energy stored in a system;
- Dynamics: Vital processes driving growth and function of an ecosystem are dominated by non-linear, feedback dynamics.

Holling (1998, p. 4) maintains that systems are moving targets, suggesting they are complex and dynamic. The function of ecosystems is dependent on profound connectivity between all its contingent components and is governed by non-linear processes (Holling, 2000). In an urban context, biomass is represented by the total accumulation of biological organic matter residing in all forms of green infrastructure, while networks and information describe form and function of biodiversity: the species, interactions between them, and the processes governing material flows and cycles. Growth towards greater complexity provides a system with resilience, and, in nature, increases the potential services drawn down by society. More recently, scientists have used concepts of ecosystem thermodynamics and complex systems theory to explain natural systems dynamics (see Demirel, 2014; Kleidon & Lorenz, 2005; Lebon et al., 2008). In accordance with these theories, natural ecosystems are open, allowing for energy and material to flow freely between them, and, under healthy conditions, each ecosystem can self-order through feedback processes enabling them to conserve energy and prevent dramatic regime shifts or even collapse—entropy (Kay et al., 2001; Norris et al., 2011).

All six ecological attributes relate systemically to generate the structure, growth, function, and ultimately resilience of ecosystems. The capacity for ecosystem evolution and adaptation is contingent on scale and the efficiency of components and networks in capturing, dissipating, storing, and using energy. The UGSF helps to structure, translate, and integrate theories of thermodynamics and complex systems into urban green space planning and assessment, and also provides a baseline for generating nature-based solutions for deep rooted design problems manifest in compact cities.

The SUCN model applies a community- and stakeholder-based approach to design and planning of urban green infrastructure. The growing popularity of civic stewardship enables communities to act as managers of urban open spaces and encourages the local community to value these areas for the service(s) they provide (Connolly et al., 2014). Incorporating fundamental aspects of UGSF into a planning strategy designed to identify relevant service algorithms for different societal goals may deliver a more effective means of facilitating networked governance processes, and building collaboration between public sector, private enterprises, and civic stewardship groups. The SUCN model is an ecosystem-based but urban-driven open framework specially designed for co-working on different elements of system growth towards the formulation of environmental sustainability and human wellbeing. Ecosystem services hierarchy model emphasizes the dependency of cultural services on regulating and provisioning services (Figure 1). At the top of a "services hierarchy" are the cultural services, and these are contingent on the effective functioning of the ecosystem, which, in turn, is dependent on the status of ecological attributes. Increasing rates of environmental change coupled with growing pressures from rapidly shifting socioeconomic and political baselines require planning solutions that are both integrated and systemic across all levels of the cultural landscape (Schick et al., 2017). The SUCN framework is based on a systemic analysis technique called MARISCO (see Ibisch & Hobson, 2014) and harnesses the participatory efforts of the target community to implement contextualized actions that promote adaptive management planning across human—ecosystem interfaces. Participatory modelling methods can support systems thinking in practice by facilitating shared understanding and knowledge of the structure and dynamics inherent in complex socio-ecological landscapes (Duboz et al., 2018). Implementing SUCN is a collective endeavour. In the last two decades, community-based action has played a fundamental part in the development of strategies for sustainable land use and building effective coalition within communities requires large scale participatory strategies that favour a non-dominant culture (Hubacek & Mauerhofer, 2008). The role of town and city municipalities in forging the establishment of "land trusts"—private-public property regimes or partnerships that permit greater shared control over use of urban green space—is essential to the process.

Both models, UGSF and SUCN, represent the natural and cultural components of a deeply interconnected complex ecosystem. The status and condition of the KEA determines the functional effectiveness of the ecosystem which in turn regulates the services derived by the local community. Human intervention or impact at any level or point in the ecosystem will result in both linear and non-linear meta-systemic feedback dynamics. An example of the cascade effect between natural and human attributes in cultural ecosystems is evident in many historical European cities that are characterised by well-established public gardens and parks with water bodies and avenues of mature shrubs and trees.

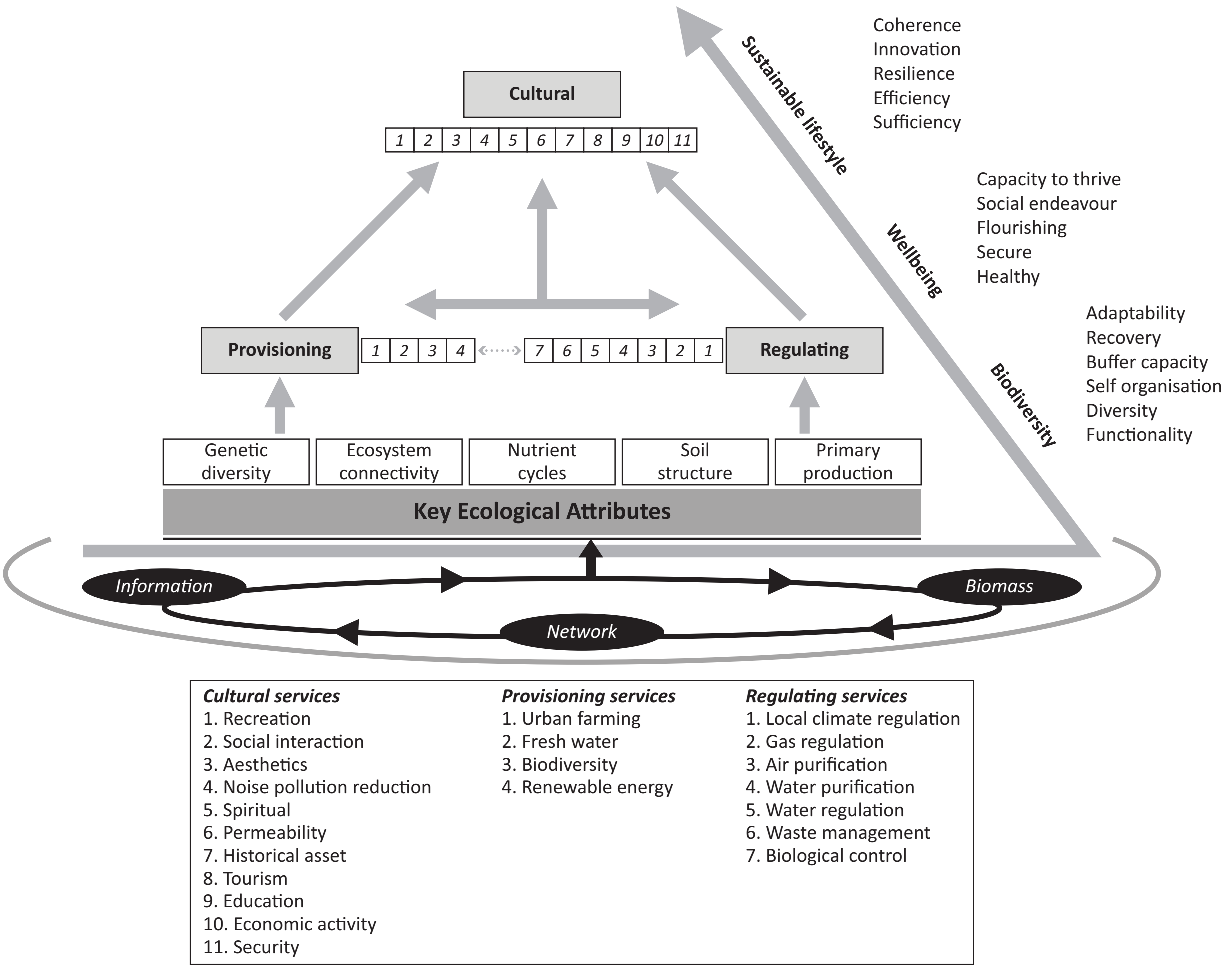

Figure 1. Ecosystem services hierarchy model emphasises the dependency of cultural services on regulating and provisioning services. A sustainable lifestyle is contingent on maintaining effective ecological structure and function.

A number of native wildlife species have adapted to urban conditions and contributed towards improving the function of ecosystems, enabling them to degrade (capture and use of energy) incoming solar radiation more effectively, thus improving thermal comfort, air quality, urban drainage, and human wellbeing (Tratalos et al., 2007). Recent research suggests that people who move to greener urban areas are associated with significant sustained improvement in health (Alcock et al., 2014).

The two-model approach to ecosystem-based design and planning embraces concepts of spatial and functional complementarity that require a set of heuristic design principles to help transition theory into practice. We propose six design principles for ecosystem-based design and planning for urban green infrastructure, which are the following:

1. Recognise and work within the natural spatial and temporal scales of the ecosystem, and take account of ecological dynamics that produce varying temporal scales and lag-effects (includes natural succession, ecosystem and species lifecycles, plant, and animal species-area relationships);
2. Ensure the conservation of ecosystem structure and function across natural space-time scales with particular attention to biomass, natural networks and connectivity, and the diversity of natural forms (includes diversity of native species and functional groups, natural patch diversity and heterogeneity, natural biomass production and storage above and below ground, hydrological regime, and hydro-geomorphological dynamics);
3. Take account of both short and long-term ecosystem changes that may affect function-area dynamics, species-area relationships, flow of energy and materials through an ecosystem, species persistence, and ecosystem resilience;
4. Consider ecological integrity of the target site by adopting a meta-systemic perspective that takes account of the relationships with adjacent sites and ecosystems in the neighbourhood and wider landscape;
5. Involve all relevant members of society and academia in a community-based participatory approach and consider all forms of pertinent knowledge and information;
6. Play an integral part of larger structure plans with a clear understanding of the contribution made to wider landscape ecosystem function by developing site-specific sustainable ecosystem-based planning.

4. A Case Study: Essex Climate Action Recommendations for Green Infrastructure

In 2020, the Essex County Council, located in the east of England, established a climate action commission to help develop an ambitious strategy to combat the problems of climate change. The Commission consists of a multi-stakeholder group of experts from a wide range of disciplines, including scientists and practicing professionals in agriculture, urban development, and water resource management (ECA Commission, 2021). A priority field for the Commission is to develop recommendations for green infrastructure with the aim of achieving, by 2030 and 2050, a transformation in the way land is managed in order to deliver the target for net zero carbon as quickly as possible (ECA Commission, 2021). In their example, the Essex County Council adopts a broad description for green infrastructure that includes natural and rural land cover types. The recommendations propose an integrated ecosystem-based approach with the purpose of delivering multiple benefits to local communities including nature recovery, improved soil health, improved air and water quality, reduction in flooding and urban heat island effects, and gains in human wellbeing by increasing amenity opportunities. One of the key recommendations is to manage 30% of all land in Essex as a natural green infrastructure to promote the enhancement of biodiversity and the natural environment: 25% by 2030 and 30% by 2040. Another recommendation is to create 30% greening of our town, villages, and new developments by: increased greenspace creation, naturalising existing green space, greening the public realm, and developing SUDS (ECA Commission, 2021).

A key recommendation for climate action is the establishment of a climate focus area (CFA), representing 30% of landcover for Essex, and taking in the catchments of the Blackwater and Colne rivers (Figures 2 and 3). The total population within both catchment areas is approximately 901,700, with 307,600 people located in the main cities and towns, including Colchester. The remainder are scattered across villages, hamlets, and isolated farm settlements. River catchments are large scale features dominated by the ongoing dynamics of rivers and wetlands. Many continue to support rich environmental legacies and provide essential connectivity in modified landscapes. The projection for the greater Essex population increase is over 18% to approximately 2.1 million by 2040 which will put greater pressure on the existing landscape resources. Across Europe, almost all catchments have been altered by land use change but continue to provide important ecosystem services to settlements. The CFA represents a hierarchically organised and interconnected ecosystem and a model for landscape scale design and planning for green infrastructure. The thinking behind the selection of a defined area of operation is pivoted on the biosphere reserve concept of developing sustainable solutions for the multiple use of natural resources where conflicts of interest frequently impact on both environmental conditions and social wellbeing. Targeting a designated area encourages investment in more intensive and focused action but also opens opportunities to develop and implement integrative strategic planning. In the case of the Essex CFA, recommendations for accelerating sustainable farming methods and transitioning local food systems, and for

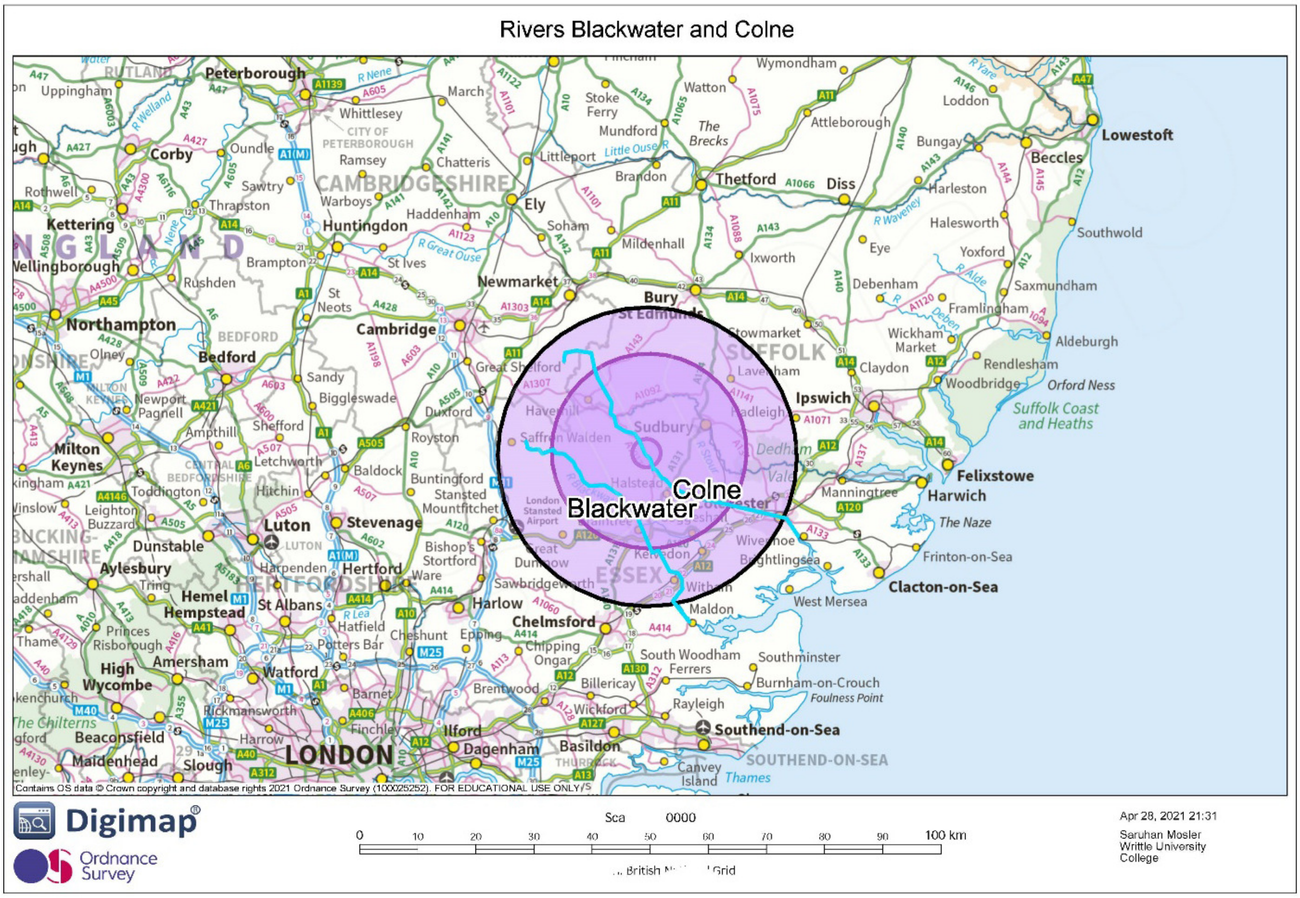

Figure 2. Rivers Blackwater and Colne in Essex. Source: Authors' work, modified after Digimap (https://digimap.edina.ac.uk).

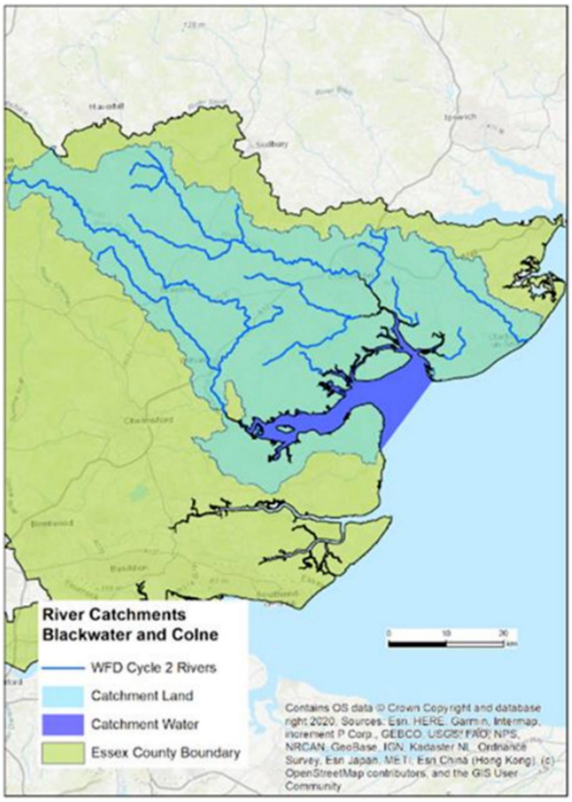

Figure 3. The proposed CFA for Essex. The chosen areas comprise the Colne and Blackwater catchments and together make up 30% of the county (ECA Commission, 2021). Source: Spains Hall Estate (n.d.).

developing nature-based solutions to mitigate flood risks and rolling out far-reaching nature recovery strategies are integrated with strategies for generating innovative green business and for transforming transport, the built environment, and energy and waste sectors towards circular, zero carbon systems. Recommendations for the CFA are set out as 2030 targets and include every parish to have biodiversity and climate emergency action plans, 30% of urban areas to be under natural green infrastructure, a doubling of native tree cover, and 30% of land cover to be managed as a natural green infrastructure (ECA Commission, 2021).

The success of ECA with all the inherent complexities of operating in a multipurpose landscape is contingent on public engagement across all levels of society. Community participatory planning is designed to enable and support community groups, schools, individuals, and businesses to innovate and implement climate actions they identify for themselves; to harness local knowledge and build local support to achieve sustainable land stewardship and natural green infrastructure recommendations; and to develop a strategy for working within communities from the start to ensure local inclusion and accountability. It is being used across Essex to facilitate the launch of a co-creative steering group of local community stakeholders, local government networks, specialists, and others to map further participation and inclusion within the county and to establish terms of reference. It is also being deployed to map and record existing activities of various sections of society (e.g., NGOs, schools, and parish councils), to establish a campaign strategy to support individual, business and community action with short term identified goals leading to longer term goals by 2050, and to create a framework for local groups to become independent in developing activities, communications, feedback, and future planning across the county (ECA Commission, 2021). Participatory planning that involves stakeholder workshops and community action groups is a systematic approach that draws together a spatial assessment of specified land cover typologies, and detailed situation analysis of the ecosystem services and benefits derived from natural attributes together with an evaluation of the vulnerabilities manifest in human use and influences (see Ibisch & Hobson, 2014). Through a process of situation analysis participants are better able to understand the deeply integrated nature of landscapes: the dependency of human wellbeing on natural ecosystem function, and the vulnerability of interdependent systems to human-induced disturbance.

The ECA recognizes multifunctionality of green infrastructure including climate, biodiversity, health and wellbeing of citizens, and flood mitigation in the sustainable future planning and design of urban landscapes. Therefore, designed landscapes are an integral part of the green network and through careful design and planning can contribute to defragmentation and landscape restoration. The benefits derived from a fully integrated and networked green infrastructure will be wide-ranging environmental and cultural services. Table 1 presents the key summary of the evaluation of ECA vision set through our proposed heuristic design principles to help transition theory into practice. Key summary presents aspects that ECA can achieve, recognize, and develop further for the ecosystem-led planning and design for the county of Essex.

Table 1. ECA and heuristic design principle evaluation chart. This table shows the evaluation of ECA recommendations through theoretical application of proposed heuristic design principles to the ECA recommendations. The key summary demonstrates proposed action points for the ECA recommendations with an enhanced approach to ecosystem-led planning and design.

ECA for Green Infrastructure (ECA Commission, 2021)	Proposed Heuristic Design Principles	Key Summary
Land use: Farmland in Essex to adopt sustainable land stewardship practices, 50% by 2030, 75% by 2040, and 100% by 2050.	(1) Recognise and work within the natural spatial and temporal scales of the ecosystem and take account of ecological dynamics that produce varying temporal scales and lag-effects (includes natural succession, ecosystem, and species lifecycles); (2) Ensure the conservation of ecosystem structure and function across natural space-time scales with particular attention to biomass, natural networks and connectivity, and the diversity of natural forms (includes diversity of native species and functional groups, natural patch diversity and heterogeneity, natural biomass production and storage above and below ground, hydrological regime, and hydro-geomorphological dynamics).	• Avoid the unnecessary use of external inputs; • Harness agroecological processes such as nutrient cycling, biological nitrogen fixation, allelopathy, predation, and parasitism; • Minimise use of technologies or practices that have adverse impacts on the environment and human health; • Utilise crop varieties and livestock breeds with a high ratio of productivity to use of externally and internally derived inputs.

Table 1. (Cont.) ECA and heuristic design principle evaluation chart. This table shows the evaluation of ECA recommendations through theoretical application of proposed heuristic design principles to the ECA recommendations. The key summary demonstrates proposed action points for the ECA recommendations with an enhanced approach to ecosystem-led planning and design.

ECA for Green Infrastructure (ECA Commission, 2021)	Proposed Heuristic Design Principles	Key Summary
Biodiversity: 30% of all land in Essex will enhance biodiversity and the natural environment by creating natural green infrastructure, 25% by 2030 and 30% by 2040.	(2) Ensure the conservation of ecosystem structure and function across natural space-time scales with particular attention to biomass, natural networks and connectivity, and the diversity of natural forms (includes diversity of native species and functional groups, natural patch diversity and heterogeneity, natural biomass production and storage above and below ground, hydrological regime, and hydro-geomorphological dynamics).	• Create a nature recovery network, using natural river corridors, the coast, other green linear features, and new green infrastructure to establish effective interlinked wildlife corridors across the county; • Integrate nature gain strategies into planning and management of all working and cultural landscapes; • Each parish to produce a complementary and integrated biodiversity action plan.
Flooding: For those properties still at risk of flooding, 75% of integrated water management and natural flood management will be developed to increase resilience by 2050	(1) Recognise and work within the natural spatial and temporal scales of the ecosystem and take account of ecological dynamics that produce varying temporal scales and lag-effects (includes natural succession, ecosystem, and species lifecycles); (3) Take account of both short- and long-term ecosystem changes that would affect function-area dynamics, species-area relationships, flow of energy and materials through an ecosystem, species persistence, and ecosystem resilience.	• Nature based flood solutions create large areas of natural green infrastructure; • Natural green infrastructure allows water to percolate into groundwater improving water quality and reserves; • Natural green infrastructure acts as a huge sponge for water: growing plants, sucking up water and organic soils, and absorbing water; • Linear river and coastal nature-based flood schemes create wildlife corridors which enhance biodiversity and contribute to nature recovery networks.
Urban Greening: 30% greening of towns, villages, and new developments by: increased greenspace creation, naturalising existing green space, greening the public realm, and developing SUDS.	(2) Ensure the conservation of ecosystem structure and function across natural space-time scales with particular attention to biomass, natural networks and connectivity, and the diversity of natural forms (includes diversity of native species and functional groups, natural patch diversity and heterogeneity, natural biomass production and storage above and below ground, hydrological regime, and hydro-geomorphological dynamics).	• Increases biodiversity and creates wildlife corridors ("green veins" and "greening-the-grey"); • Lowers the "heat Island effect" in built up areas; • Provides "green-exercise" benefits to mental health; • Reduces pollution; • SUDS reduces urban flooding.
CFA: Create a CFA to accelerate action and provide exemplars, adopting sustainable land stewardship practices (100% by 2030) and natural green infrastructures (30% by 2030).	(4) Consider ecological integrity of the target site by adopting a meta-systemic perspective that takes account of the relationships with adjacent sites and ecosystems in the neighbourhood and wider landscape.	• To serve as a pathfinder and pilot area, accelerating best practice in sustainable land management; • To act as an investment "attractor" for innovative green business and for pioneering new sustainable farming methods; • A focus area for transitioning local food systems and cultural eating habits; • To demonstrate ambitious and sustained nature recovery strategies; • A multi-sectoral project site for integrating and intensifying action following recommendations from the special interest groups (transport-built environment, energy and waste, and community).

Table 1. (Cont.) ECA and heuristic design principle evaluation chart. This table shows the evaluation of ECA recommendations through theoretical application of proposed heuristic design principles to the ECA recommendations. The key summary demonstrates proposed action points for the ECA recommendations with an enhanced approach to ecosystem-led planning and design.

ECA for Green Infrastructure (ECA Commission, 2021)	Proposed Heuristic Design Principles	Key Summary
Engagement: Ensure collaboration and engagement by carrying out a participatory community process, catalysing communities, farmers, landowners, and individuals, and encouraging personal and community action in the CFA and the whole of Essex.	(5) Should involve all relevant members of society and academia in a community-based participatory approach and consider all forms of pertinent knowledge and information.	• Enable and support community groups, schools, individuals and businesses to innovate and implement climate actions they identify for themselves; • Harness local knowledge and build local support to achieve sustainable land stewardship and natural green infrastructure recommendations; • Develop a strategy working within communities from the start to ensure local inclusion and accountability.
Knowledge and Decision Support: Developing effective monitoring and evaluation, an integrated sustainability appraisal framework, an Essex climate observatory, and a knowledge and decision support framework.	(5) Should involve all relevant members of society and academia in a community-based participatory approach and consider all forms of pertinent knowledge and information.	• Develop a monitoring and evaluation programme within an Essex climate observatory and involve citizens and researchers in data gathering activities across the CFA; • Develop an integrated sustainability appraisal framework to support the Climate Action Programme in Essex, the CFA, and stakeholders needs; • Collate and curate relevant data within an Essex knowledge platform and decision support framework; • Establish a baseline audit for the CFA.

5. Conclusions

To help mitigate the problems of urban growth and densification, urban planners and designers have recently been using a range of models for urban green infrastructure to provide sustainable, resilient, and healthy urban environments. Notwithstanding, the need remains to strengthen the framework for design and planning by structuring it around ecosystem-based approaches. An ecosystem approach to planning is predicated on the physical and biological structures and processes that determine the function of ecosystems and ultimately support human wellbeing; however, there are few examples of urban green infrastructure design that demonstrate the complex interrelationship between ecological function and social wellbeing. In part, this may be attributed to the lack of heuristic design principles for urban green infrastructure that draw on an understanding of the relationship between specific ecological and social concepts. Ecology already has a wide application in landscape architecture and planning with a strong focus on species persistence and movement, patch dynamics, connectivity, and disturbance patterns. Less attention is given to ecosystem growth, function, and dynamics, or to ecosystem thermodynamics, and for obvious reasons. The mathematical and empirical nature of ecosystem theory is complicated enough for scientists without attempting to translate into language and practical models for landscape architects and planners. Nevertheless, a more comprehensive understanding among landscape architects and planners of ecosystem science is necessary if resilient and sustainable conditions are to be provided for urban communities, and if current policies and directives for safeguarding the environment and mitigating problems of climate change are to be met.

The purpose of heuristic principles is to help translate theory into models of practice but, even then, it is often necessary to justify and explain the origins and content of principles. The two models offered in our article, UGSF and SUCN, provide appropriate criteria and framing for the heuristic principles. Both models represent the two main domains of living landscapes: the natural and cultural environments, and are mutually complementary by virtue of the interconnectedness and systemic nature of ecosystems and communities. For instance, the process of conducting community participation encourages knowledge sharing and learning between all members of society, from scientists to managers and policy makers. Information is collectively assessed systemically before it is evaluated through consensus and finally translated into agreed plans and strategies. Community participatory planning is carried out in the context of the environmental setting—the physical character of the landscape. In other words, the KEA are evaluated within a broad understanding of nature-based values people attach to green infrastructure. The ECA recommendations represent the role of ecosystem-led planning approach at all scales and levels, including smaller scale interventions to larger rural planning approach, to create a robust green infrastructure system across the county. The vision and targets for green infrastructure set out by ECA Commission reflect clearly three principles of an ecosystem-based approach: First, by adopting a landscape approach to planning, the patterns and processes lending structure and driving change are better understood; second, by working with the grain of nature, outcomes are more likely to be sustainable and resilient; and third, to achieve a coherent and fully integrative strategy, a bottom-up, full participatory approach is a prerequisite. Finally, an ecosystem approach also facilitates learning within the community. It encourages knowledge sharing, continual evaluation, and adaptation, essential attributes for operating in situations that are rapidly changing.

The relationship between humans and the environment has increased levels of complexity and vulnerability in natural ecosystems to the extent of precipitating rapid climate change and plummeting decline in biodiversity (Intergovernmental Panel on Climate Change, 2019; Schick et al., 2017). Until recently, socio-environmental problems were analysed and addressed using linear, cause-effect principles, and took little account of the deeply interconnected nature and non-linear character of ecosystems. Recent changes in the way science analyses complex systems have opened up opportunities to develop holistic models for land use design, planning, and management. Innovative design and new methods of practice will have to demonstrate flexibility, adaptability, and systemic function if we are to future-proof our living landscapes.

Conflict of Interests

The authors declare no conflict of interests.

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Article

Classification of Landscape Physiognomies in Rural Poland: The Case of the Municipality of Cekcyn

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Abstract
This article presents a methodology and the results of the classification of the rural landscapes physiognomies conducted on the study area located in the municipality of Cekcyn, Poland. The study aimed to develop a landscape identification method that would combine natural, cultural, and visual criteria with which to implement the provisions of the European Landscape Convention. The realization of the European Landscape Convention in Poland is incomplete due to the lack of practical application of landscape assessment in land management and spatial planning at the commune level. The research was intended at helping to fill this void. The study develops a method using which it will be possible to protect the diversity and beauty of Europe's rural landscapes more effectively. The goal has so far been of little scientific interest in Poland. The physiognomy of the studied area was analyzed with the use of commonly available spatial data and by means of field studies. Physical-geographical units and cultural characteristics have been designated based on spatial databases. Landscape patterns were identified by analyzing visual fields with the use of both GIS applications and field studies. This practice made it possible to determine physiognomic units of the landscape which are internally coherent and relatively homogeneous in terms of physical-geographical, cultural, and visual features. Identifying the landscape physiognomy within the designated landscape physiognomic units serves to harmonize spatial alterations in the area of rural communes in processes of land management and planning.

Keywords
land management; landscape assessment; landscape physiognomy; Poland; rural areas

Issue
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1. Introduction

The European Landscape Convention (hereafter referred to as ELC, the international convention signed by the parties in Florence, 2000, ratified in Poland in 2005) shifted the focus from landscape protection to landscape management of identified areas. Primarily, the visual aspect of landscape represents its natural and cultural phenomena (Bell, 2012). Its recognition provides a prerequisite to harmonizing natural and social processes and to support spatial decision-making. The visual landscape assessment assumes an active human role in shaping the space. For this reason, the inclusion of visual landscape assessment in management and planning procedures is closely related to maintaining spatial order (Antunes et al., 2009; Bishop & Phillips, 2012; Özesmi & Özesmi, 2004). This statement is confirmed by the systemic functioning of landscape assessment methods applied in the spatial planning of many European countries and worldwide (e.g., Cherrie, 2007; Fairhurst, 2004; Natural England & Department for Environment, Food & Rural Affairs, 2014; Tudor, 2014; Wascher, 2005). The present article aimed to develop and test a methodology for visual landscape assessment in line with the holistic approach proposed in the ELC to be directly applied in spatial planning of rural municipalities in Poland. The study refers to the concept of landscape as physiognomy of an area, popularized in Poland (Bogdanowski, 1999; Bogdanowski et al., 1981, p. 8; Chmielewski et al., 2017, 2019), and merges map-based and aesthetic methods used by Polish researchers separately within the disciplines of physical geography (e.g., Chmielewski et al., 2014; Sowińska & Chmielewski, 2008), as well as within architecture and urban planning (e.g., Forczek-Brataniec, 2018; Myczkowski et al., 1998).

Each area has its character formed by physical shapes and their arrangement identified depending on people's associations and memories. For this research, landscape physiognomy was defined as a spatial pattern, specific and relatively stable, which is possible for an observer to recognize. The spatial pattern provides a dynamic composition created by a unique structure of elements, as well as natural and/or cultural features, such as geological formations, landform, settlements, forms of greenery, or types of land use and development (Antrop, 2000; Novák, 1950/1997). People who experience the patterns can read them and use them "as a guide for landscape restoration" (Bell, 2012, p. 13). The adopted extensive landscape composition arises as to the visual motifs from the viewpoints located on the designated routes (Appleyard et al., 1964; Bogdanowski, 1976, 1999; Forczek-Brataniec, 2008) and of images (Cullen, 1961, pp. 17–19). The perceived composition is a kind of mental, three-dimensional model of the arrangement of landscape elements and their features; or a kind of holistic concept of the landscape structure (Kaplan et al., 1998, p. 18); or a "landscape scenario" (Böhm, 2016, p. 286). The perceived composition depends on the availability of observations or viewpoint connections from scenic routes. The consideration of the perceived spatial composition in the process of landscape patterns identification allows for a relative agreement between the visual experiences of observers and the results of landscape classification based on physical, measurable factors to be obtained.

The perceived landscape is an integral phenomenon, but the analysis of its physiognomy can be done by a functional examination of the separate layers of factors as follows:

- A layer of natural characteristics, which consists of biotic and abiotic natural resources (Chmielewski et al., 2015; Richling & Ostaszewska, 2005), such as geology, soils, relief, water, and vegetation. These resources provide a genetic skeleton of the current landscape;
- A layer of cultural characteristics, which consists of the elements and features of any anthropogenically transformed natural cover and cultural cover (Bogdanowski et al., 1981). Contemporary land use and its historical variability are examined within this layer of analysis;
- A layer of visual characteristics, which defines the accessibility of the views, aspects of landscape exposure, and the spatial composition of the area (Bogdanowski, 1976; Böhm, 2016). Within this layer of analysis, it becomes possible to explain how the material attributes of the landscape, both natural and cultural, become apparent to the observer (Litton & Tetlow, 1978, p. 52; Smardon et al., 1986, p. 159; Tetlow & Sheppard, 1979, pp. 117–124).

The comparison of physical, geographical, and cultural characteristics, along with the perceived exposure and spatial composition, leads to the determination of somewhat internally homogeneous areas called "landscape physiognomic units" (LPUs).

2. Materials and Methodology

2.1. The Scheme of LPUs' Identification Process

The LPUs' identification process is presented in the block diagram in Figure 1.

2.2. The Study Area

The study was conducted in the Kuyavian-Pomeranian Voivodeship, namely in the Cekcyn municipality, whose area totals 253.3 km^2. The research area of 36.7 km^2 is located in the west part of the Cekcyn municipality, almost entirely on the Świecie Upland (mesoregion serial no. 314.73 in the classification system by Solon et al., 2018), next to the Brda Valley mesoregion (no. 314.72) towards the west, and within the Tuchola Forest mesoregion (no. 314.71) towards the north and north-east. The municipality recognized it as a homogeneous settlement and agricultural zone in the Study of Spatial Development Conditions and Directions (Cekcyn Municipality Council, 2018). The area is covered by a mosaic of fields, forests, settlements, and lakes (the percentage of land cover areas equal 24.8%, 6.75%, 1.8%, and 2.2%, respectively).

The area adopted for research is fully covered by nature and landscape protection programs, represented by the Tuchola Landscape Park, its buffer zone protection plan, and the Śliwice Protected Landscape Area. These protection measures cover 70% and 30% of the study area, respectively, while local plans only apply to 2.5% of the total area.

2.3. Desk Study

Cartographic studies included the natural and cultural landscape factors of the examined area and the fields of visibility. A dozen or so auxiliary maps were made (Table 1), which were used to identify the following auxiliary areas:

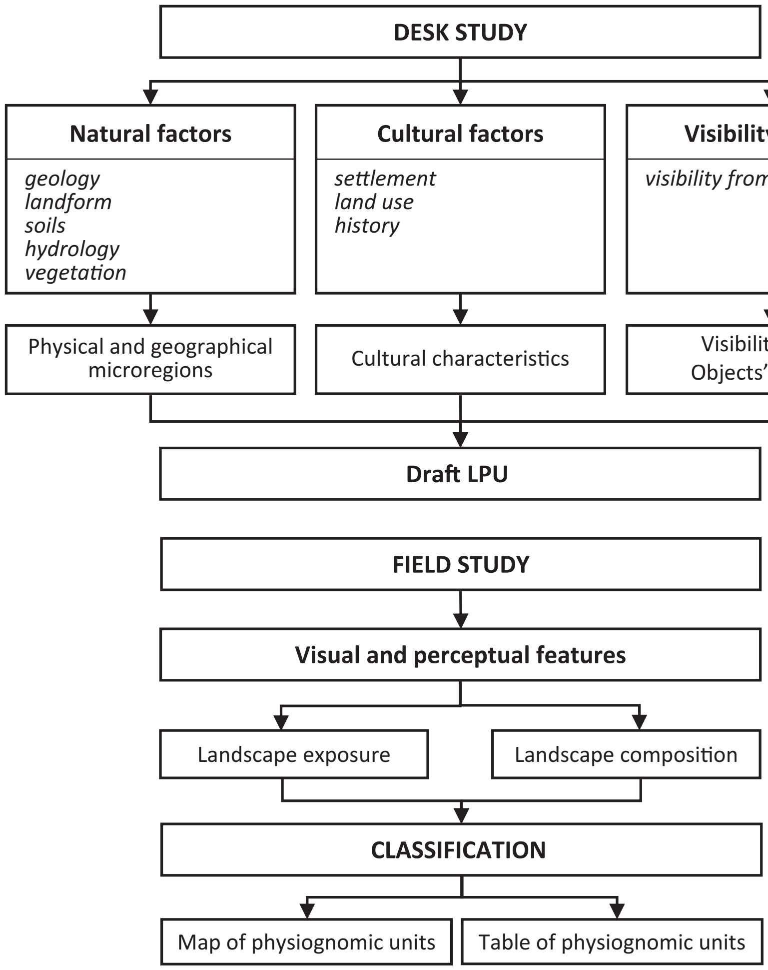

Figure 1. Methodology of identification of LPUs.

- Physical–geographical microregions: Polish geographers designate them as the most minor basic physical–geographical units: areas of similar genesis and geological structure, soil types, and landforms. They partly correspond to landscape units in the English-language research tradition, which are consistent in their topography, geology, and land cover. Physical–geographical units were determined by means of the guiding factors terrain and geological structure. Their initial outline was determined by analyzing hypsometric, geomorphological, and water surface maps (Table 1, no. 1–3). Then, fragments of boundaries characterized with an uncertain sequence were detailed based on an orthophoto map and maps which present such factors as plants cover or soil fertility of the area (Table 3, no. 4–7);
- Cultural characteristics: areas with relatively homogeneous land use and land cover, along with the history of their transformation. They were determined following the analysis of archival and modern cartographic sources. The variability was assessed by comparing past and contemporary shapes of fields and homestead locations (Table 1, no. 13). The types and distribution of cover elements and features were analyzed considering the types of their usage: forests, mowed and overgrown meadows, and developed areas (Table 1, no. 8), fields surface patterns (Table 3, no. 14), development types (Table 1, no. 15), and the antiquity of the units (Table 1, no. 11–12);
- Fields of visibility were determined based on computer modeling of viewshed from the essential local roads. A set of analyses into horizon and viewing plan was prepared for all bicycle routes in the study area. The surface sizes of areas visible from bicycle routes and other roads selected for the studied area were compared (Table 1, no. 17–18). Moreover, the analysis of the visibility range from the church tower in Cekcyn was also made (Table 1, no. 19). Insubstantial walls of the landscape rooms were indicated, along with well-exposed elements and areas. The results of computer modeling of viewshed were used for subsequent field studies of landscape exposure and composition.

The analytical units are shown in Figures 2 and 3. A full description of the desk study tools and measurements is listed in Table 1.

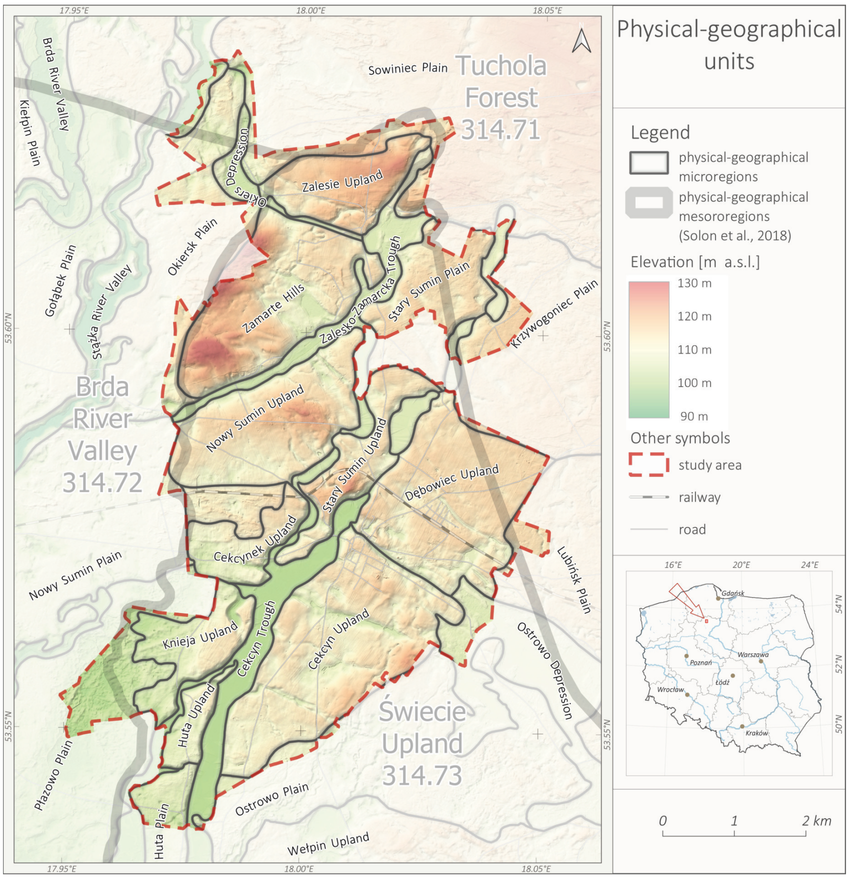

Figure 2. Designated physical–geographical units in the study area.

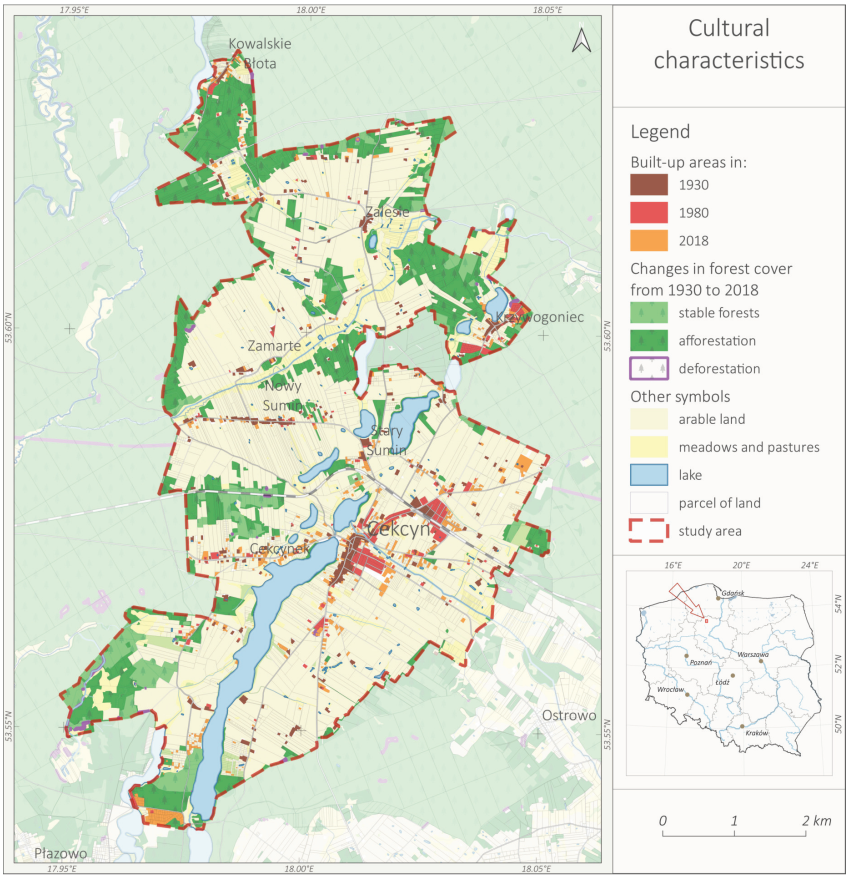

Figure 3. Designated cultural characteristics in the study area.

Table 1. List of prepared auxiliary maps.

No.	Title	Type of factors	Data source	Methods/comments
1	Surface Waters	Natural factors	DoTO10k, ORTHO	The separation of surface waters on DoTO10k was updated based on the orthophoto map.
2	Hypsometry		DTM, DoTO10k, LaBR	A translucent shading layer was applied to the hypsometry to enhance the relief.
3	Orthophoto Map		ORTHO, LaBR	
4	Plant Cover		ORTHO, DoTO10k, LaBR	Separation of plant cover based on DoTO10k and LaBR land use contours are detailed based on the orthophoto map.
5	Geomorphology		DGMP50k, DoTO10k, LaBR	
6	Soil Fertility		LaBR, DoTO10k	Soil fertility on agricultural land according to LaBR bonitation classes.
7	Physical and Geographical Microregions		DGMP50k, DTM, ORTHO, DoTO10k, LaBR	Regionalization by using the deductive method of guiding factors (mainly relief and geological structure; locally: soils and vegetation).
8	Land Use	Cultural factors	DoTO10k, LaBR	The classification of developed areas was the result of the generalization of LaBR and DoTO10k land use divisions.
9	Forms of Nature Protection		NPF, DoTO10k, LaBR	
10	Protection and Care of the Material Cultural Heritage		SoSDCaD, MCP, MGI_25, DoTO10k, LaBR	Location of objects contained in the municipal monument records based on independent geocoding of addresses of buildings. Some surface separations were generalized to points due to the incomplete description of their location on the monument cards.
11	Spatial Development of Buildings in the Years 1930–2018		MGI_25, Topo_10_65, DoTO10k, LaBR	Archival 1:25,000 Messtischblätt maps were not included due to the considerable time heterogeneity of individual sheets covering the analyzed area.
12	Change in the Range of Forested Areas Compared to the State as of 1930		MGI_25, Topo_10_65, DoTO10k, LaBR	Archival 1:25,000 Messtischblätt maps were not included due to the considerable time heterogeneity of individual sheets covering the analyzed area.
13	WIG Maps From 1930–1932 Compared to Records Contained in the Land Registry From 2018		MIG_25, LaBR	
14	The compactness of the Shape of Registration Plots		DoTO10k, LaBR	The Kostrubiec index was applied to analyze the compactness of the shape of cadastral plots (Kostrubiec, 1972): $S = \frac{\text{quadrat of perimeter of the figure}}{\text{area of the figure}} - 12.56$
15	Development Management		SoSDCaD, DoTO10k, LaBR	Developed areas and those intended for development in SoSDCaD, as well as areas provided for by the local plan, together with their dominant function, are presented.
16	Map of Cultural Coverage Units		DoTO10k, LaBR	Additionally, the map presents compact buildings, understood as a group of a minimum of five buildings, except for facilities with a purely economic function, the longest distance between which does not exceed 100 m (Sejm of the Republic of Poland, 1995). Clusters of buildings that meet the statutory criteria of compact development were separated using the DBSCAN algorithm of the QGIS program.

Table 1. (Cont.) List of prepared auxiliary maps.

No.	Title	Type of factors	Data source	Methods/comments
17	Visibility From Roads	Visibility factors	DSM, DTM, DoTO10k, LaBR	Visibility range calculated using the "Visibility Analysis" plug-in of QGIS—"binary viewshed" function. Adopted observation height: 1.65 m; analysis range: 10 km. Observation points are spaced every 50 m along the roads. The analysis was conducted on a modified DSM model with a spatial resolution of 4 m, from which trees within a radius of 15 m from the axis of the analyzed roads were excluded.
18	Horizon Visibility	Visibility factors	DSM, ORTHO, Topo_10_65	Horizon visibility calculated using the "Visibility Analysis" plug-in of QGIS—"horizon full" function. Adopted observation height: 1.65 m; analysis range: 10 km. Observation points are spaced every 50 m along the roads. The analysis was conducted on a modified NLCM model with a spatial resolution of 4 m, from which trees within a radius of 15 m from the axis of the analyzed roads were excluded.
19	Visibility of the Church	Visibility factors	DSM, ORTHO, DoTO10k, LaBR	Visibility range calculated using the "Visibility Analysis" plug-in of QGIS—"binary viewshed" function, based on the DSM model with a spatial resolution of 4 m.

Notes: Explanation of abbreviations: DoTO10k—database of topographic objects; LaBR—lands and buildings registry; NPF—nature protection forms; DSM—digital surface model with one-meter resolution generated from LiDAR data; DTM—digital terrain model with one-meter resolution generated from LiDAR data; ORTHO—orthophoto map; MCP—monument care program; DGMP50k—detailed 1:50,000 geological map of Poland; SoSDCaD—the study of spatial development conditions and directions thereof; Topo_10_65—1:10,000 topographic map, "1965" coordinate system; MGI25—detailed 1:25,000 map by the Military Geographic Institute.

2.4. Field Study

Field studies included a general assessment of the elements and features of open landscapes in terms of their visual impact. The studies mainly focused on identifying the visibility ranges in open areas from local roads and determining the views' nature. Three bicycle tourist routes running through the research area along the most critical local roads were selected for analysis. Visual features pre-recognized with a digital application have been compared to the results of field studies. Two aspects of the landscape visual perception were explored: the exposure and the composition. The former explains how the observer may see the landscape; the latter describes what can be seen by the observer. During the desk studies, sequences of viewpoints along the scenic road network were indicated, together with the areas of visible surfaces (Table 1, no. 17). The quantitative results made it possible to select the viewshed of the most significant regions or those of the maximum potential for a composition cognition. The maximum view contours were identified by horizon visibility measurement from the points on the road network (Table 1, no. 18). In this way, viewing corridors and intangible walls, noticeable while observing, could be precisely established.

During field studies, substantial, translucent, and intangible walls of the landscape enclosures were indicated, followed by view connections between them. Moreover, the nature of view openings—limited or panoramic—was determined (see Figure 4). Measuring the visibility range of dominant features leads to determining significant motives of landscape composition perceivable from viewpoints or scenic routes. The church tower in the study area was considered a dominant feature, so the visibility of the church was examined (Table 1, no. 19) and then confirmed by observation from the network of roads. Spatial compositions were interpreted within the studied area under the adopted and previously described principles, such as an arrangement of planes, solids, lines, or points, and their visual features perceived from scenic routes (see Figure 5).

3. Results

As a result of the study, internally consistent LPUs (i.e., synthetic units with a distinctive pattern) were identified as those that stand out from the neighboring units in terms of natural and cultural features and the visual perception thereof. The reconciliation process of synthetic LPU involved comparing the nature and disposition of physical–geographical, and cultural attributes with their visual features (Ode et al., 2008). This process was intended to obtain the greatest possible internal uniformity and coherence in terms of the material structure and spatial composition. In debatable cases, the final path of the boundaries was determined by following the guideline of the area perception as a visual whole. The identified LPUs are mapped in Figure 6 and listed in Table 2 (see column 3A in Table 2). They refer to the physical–geographical mesoregions designated in Poland according to the regionalization developed by Solon et al. (2018; see column 1 in Table 2) and with regards to the

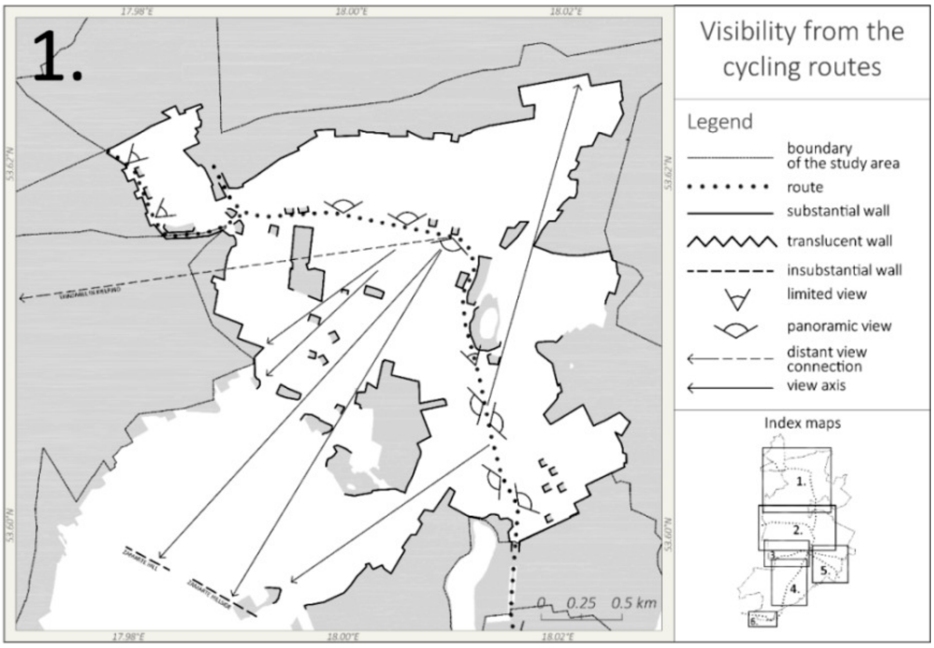

Figure 4. Analysis of landscape exposure of route 1 and characteristics of the limited fields of view.

landscape subtypes adopted in Poland (see columns 2A and 2B in Table 2). The forms of relief and the interconnected nature of land cover within identified LPUs are described in columns 3B and 3C of Table 2. Each LPU has a proper name assigned along with a description aligned with the numeric list (e.g., H8—Cekcynek Hill). Its first part refers to toponymy and identity and represents the cultural landscape features, while the second part defines topographic features and represents the natural landscape. Both indicate the perception of the place.

A rural landscape dominates the majority of the studied area with a mosaic of small fields. It has the form of a large forest clearing for settlement purposes. The area almost entirely coincides with the range of the undulating moraine upland classified as the Świecie Upland. This part of the studied area includes 10 separate units located on hills and three plain landscape units that lie partly within its boundaries. In the case of the Ostrowo Depression, its north-western edge remains the only part that interferes with the studied zone. The area includes 12 narrow and relatively shallow valleys, usually covered with meadows and bushes, ranging from the northeast to the southwest. These are short sections of water-free, post-lakes channels, or melt channels. The western, northern, and eastern ends within the study's boundaries also include numerous fragments of plains and depressions, mostly forested ones assigned to the mesoregions of the Tuchola Forest and Brda Valley.

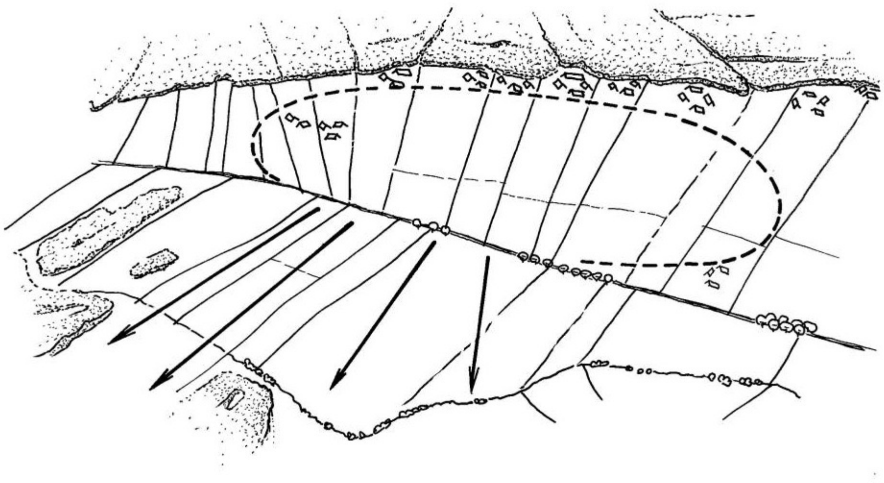

Figure 5. A synthetic sketch of the spatial composition for the sequence of views from route 1. The northern side of the route: a completely uncovered, slightly rising field with radial bounds, enclosed by the forest, and a few buildings; the southern side of the route: a panoramic view of the undulating terrain with irregular fields and distant forests.

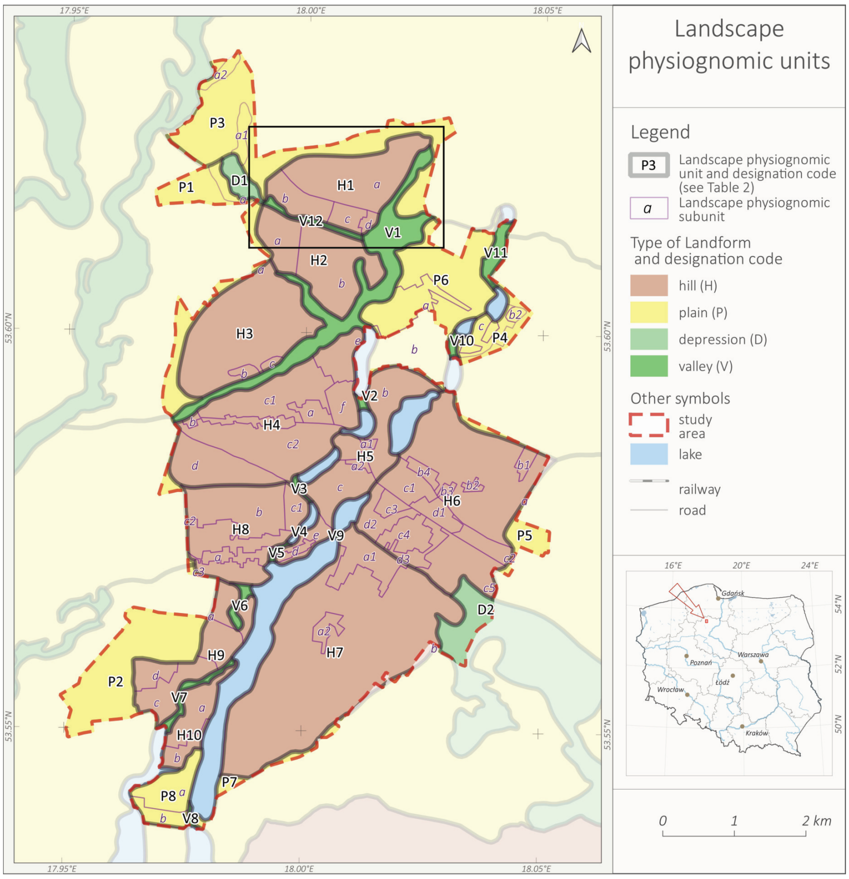

Figure 6. LPUs and subunits. The area selected for a detailed description (marked with the rectangle).

Table 2. Classification of the landscape units of the study area with integrated description of subunits.

1. Regional context	2. Subregional context		3. Local context			
			LPU			
	2A	2B	3A	3B	3C–3E	
Brda Valley Landscapes 314.72 (Solon et al., 2018)	Plains	Forest landscapes: Alluvial and alder forests (A.3c)	P1 Okiersk	Undulating plain	a. Compact village building development	
					b. Forests: New coniferous forest	1 2 3 4
			P2 Płazy	Undulating plain	a. Mid-forest field with compact buildings and bushes	
					b. Forest perforated with glades	
	Depressions		D1 Okiersk	Flat plain	Mosaic of meadows, fields, and trees	

Table 2. (Cont.) Classification of the landscape units of the study area with integrated description of subunits.

1. Regional context	2. Subregional context		3. Local context			
			LPU			
	2A	2B	3A	3B	3C–3E	
Landscapes of Tuchola Forest 314.72 (Solon et al., 2018)	Plains	Forest landscapes: coniferous forests (A.3b)	P3 Sowiniec	Undulating plain	a. Compact rural and summer accommodation development	1 2
					b. Forests: New coniferous forest	
			P4 Krzywogoniec	Flat plain	a. Forests: New coniferous forest	
					b. Compact village building development	1 2 3
					c. Fields encrusted with housing, summer, and agricultural development	
			P5 Lubińsk	Undulating plain	Mosaic of forest, meadows, and bushes	
Landscapes of Świecie Upland 314.73 (Solon et al., 2018)	Hills	Rural landscapes with a mosaic of small fields (B.6c)	H1 Zalesie	Plateau	a. Ribbon-shaped, regular arable fields with a radial layout of a dispersed village building development	
				Series of hills	b. Regular, elongated fields, inlaid with forests and building development	
				Hill	c. Irregular arable fields	
					d. Compact village building development	
			H2 Zalesie-Zamarte	Hill	a. Regular extender fields with dispersed buildings	
				Plateau	b. Mosaic of dispersed village fields cut by forest	
			H3 Zamarte	Hill	a. Ribbon-shaped farmlands inlaid with dispersed village building development	
					b. Buildings of a compact post-parcel village	
					c. Buildings surrounded by forest	
			H4 Nowy Sumin	Top of the hill	a. Forest and building mosaic	
				Hillslope	b. Buildings in a compact village	1 2
					c. Ribbon-shaped, regular fields inlaid with trees	
				Base of the hill	d. Irregular fields inlaid with trees	
				Carved hills	e. Forest	
					f. Small, rectangular fields with mixed arrangement	
			H5 Stary Sumin	Plateau	a. Compact building development	1 2
					b. Mosaic of fields, forests, and building development	
				Carved hills	c. Mosaic of fields, forests, and building development	
				Plateau	d. Compact building development	
					e. Small, regular, elongated fields	

Table 2. (Cont.) Classification of the landscape units of the study area with integrated description of subunits.

1. Regional context	2. Subregional context		3. Local context			
			LPU			
	2A	2B	3A	3B	3C–3E	
Landscapes of Świecie Upland 314.73 (Solon et al., 2018)	Hills	Rural landscapes with a mosaic of small fields (B.6c)	H6 Dębowiec	Plateau	a. Mostly longitudinal fields inlaid with building development	
					b. Building development	1 2 3 4
				Undulating hill	c. Mosaic of fields, meadows, and building development	1 2 3 4 5
					d. Compact suburban housing	1 2 3
			H7 Kruszka	Undulating hill	a. Compact building development of varied character	1 2
					b. Mosaic-arranged, mostly elongated arable fields inlaid with building development	
			H8 Cekcynek	Undulating hill	a. Compact housing development	
					b. Mixed forest perforated with glades	
					c. Fields inlaid with buildings	1 2 3
			H9 Knieja	Carved hilltop	a. Mosaic of fields with buildings and young forest	
					b. Streaked fields of various sizes with buildings	
				Slope	c. Large, triangular fields d. Forest	
			H10 Huta	Undulating hill	a. Mosaic of fields with rural buildings	
					b. Residential and summer development in the bushes	
	Plains		P6 Stary Sumin	Undulating plateau	a. Mid-forest field with ribbon fields inlaid with buildings	
					b. Forest perforated with fields, meadows, and buildings	
			P7 Ostrowo	Undulating plateau	Forest	
			P8 Huta	Undulating plateau	a. Forest	
					b. Forest and bushes perforated with buildings	

Table 2. (Cont.) Classification of the landscape units of the study area with integrated description of subunits.

1. Regional context	2. Subregional context		3. Local context		
			LPU		
	2A	2B	3A	3B	3C–3E
Landscapes of Świecie Upland 314.73 (Solon et al., 2018)	Valleys	Rural landscapes with a mosaic of small fields (B.6c)	V1 Rakówka	Water-free, post-lake channels	Mowed meadows
			V2 Lakes Mętne and Zadworne		
			V3 Lakes Chłodne and Wielkie Skąpe		
			V4 Lakes Wielkie Skąpe and Małe Skąpe		
			V5 Lakes Małe Skąpe and Cekcyńskie		Mowed meadows and fields
			V6 Lake Cekcyńskie		Overgrown meadow
			V7 Lakes Cekcyńskie and Miały		Mowed and unmowed meadows and bushes
			V8 Lakes Cekcyńskie and Drzycimskie		Mowed meadows and fields
			V9 Lakes Główka and Cekcyńskie		Mosaic of buildings, meadows, trees, and bushes
			V10 Lakes Wołyczek and Okoninek		Mowed and unmowed meadows and bushes
			V11 Lakes Szczuczanek and Krzywogoniec		Mosaic of mowed meadows, fields, and trees
			V12 Zalesie	Meltwater valley	Mowed meadows, fields, and trees
	Depressions	Swamp and meadow landscapes (A.2a)	D2 Ostrowo	Flat plain	Mosaic of meadows, fields, and trees

The columns 3C–3E in Table 2 contain a combined description of cultural characteristics and perceptions. A further breakdown of LPUs into subunits where visual perception can be described is shown in Figure 7 and Table 3. In Table 3, the part relating to selected LPUs is expanded to four columns—3B, 3C, 3D, and 3E—which described, respectively, relief, land use, exposure, and composition.

It was assumed that the LPUs identification and classification aims to support spatial planning and land management, preserving the beauty, or restoring landscapes degraded by urban sprawl. The topography of lakes

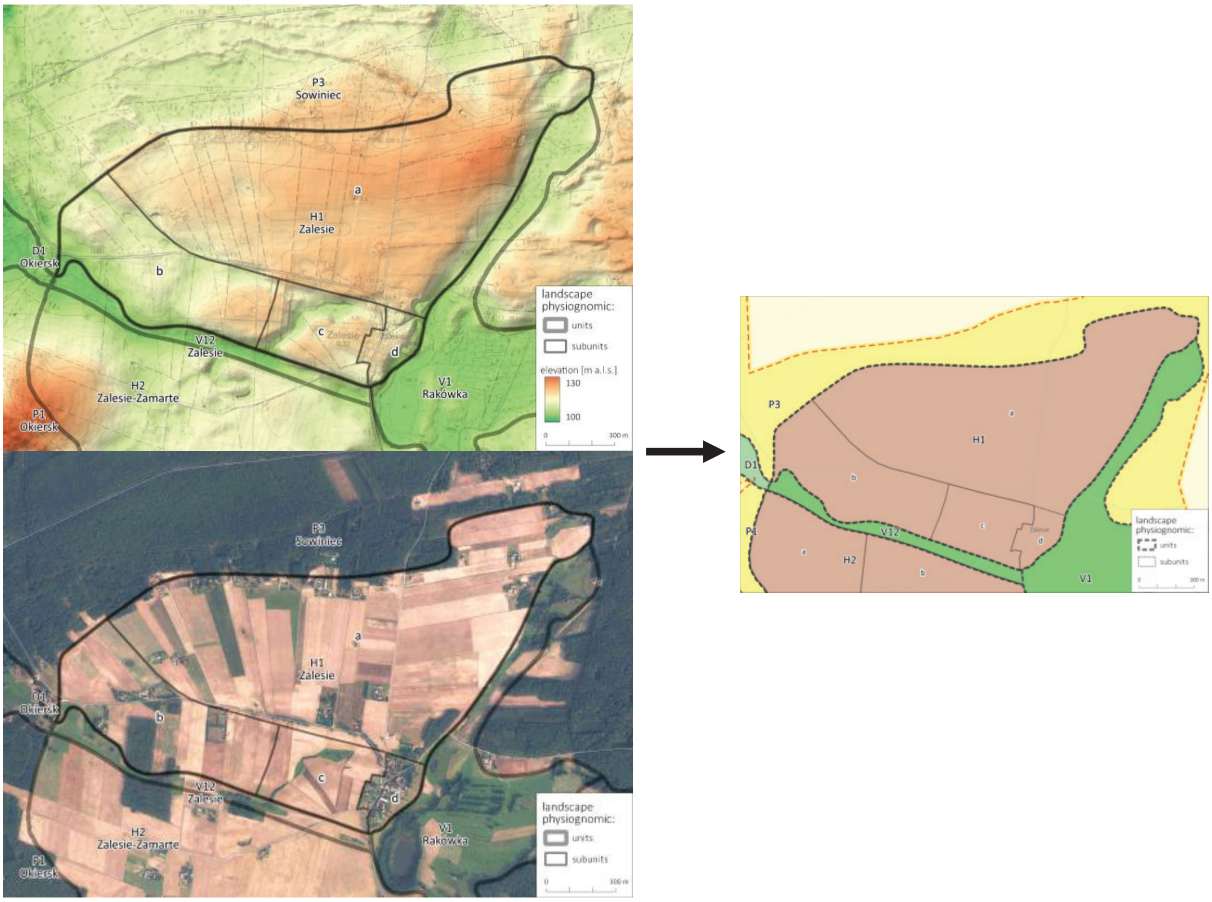

Figure 7. The subdivision of selected LPUs based on the relief and arrangement of land cover characteristics (orthophoto map).

seems essential, i.e., for the picturesqueness of the area, but to a lesser extent for building development. These areas are included in LPUs classification only indirectly. Therefore, they have not been listed in Table 2. However, the perception of lakes can still be explored from scenic land points.

4. Discussion and Conclusions

Many methods of identifying and classifying landscapes exist and serve a variety of purposes. Three main research approaches may be distinguished that differ in objectivism–subjectivism (Simensen et al., 2018).

Table 3. Extension of Table 2 regarding the description of landscape exposure and composition.

LPU 3A	Visual Perception				
	Relief 3B	Land use 3C	Exposure 3D		Composition 3E
H1 Zalesie	Plateau	a. Arable fields with a village building development	A vast, uncovered interior, visible from the view road	View plan enclosed by a forest wall inlaid with buildings	Ribbon-shaped, regular arable fields with a radial layout of dispersed farm buildings
	Series of hills	b. Arable fields with forests and building development		Open view plan	Regular, elongated fields, inlaid with forests and farm buildings
	Hill	c. Arable fields		View plan enclosed by building development	Irregular arable fields
		d. Village building development	Village buildings exposed from the view road and the surrounding fields		One-story, traditional farmhouses loosely situated with an extended front to a village road, farms at the back

The first approach is of a subjective, intuitive, and interpretive nature. It explores holistic landscape concepts by analyzing aesthetic, natural, and cultural landscape features together. This approach is represented by Landscape Character Assessment in United Kingdom (Fairclough et al., 2018; Julie Martin Associates & Swanwick, 2003; Swanwick, 2002) and various studies, e.g., in Spain (Nogué et al., 2016), Hungary (Boromisza et al., 2011), or Poland (Solecka et al., 2018). The second approach is to describe the landscape based on natural or cultural factors, which are preselected depending on the specifics of a scientific discipline. In Poland, this group of methods is represented by Solon et al. (2018) or Krajewski (2011). However, the third approach is multivariate and involves mapping a range of statistical biophysical data (Cushman et al., 2010, pp. 83–108).

The proposed procedure adopts the characterization process in the landscape character assessment methodology (Scottish Natural Heritage Tayside and Clackmannan Area Office, 2001; Swanwick, 2002; Swanwick & Fairclough, 2018, pp. 21–36). Its holistic perspective assumes that the character of a landscape depends on the interaction between the physical features of the area, as well as the process of perception and decision-making (Daniel, 2001). The method of landscape characterization includes associations or memories. It is, thus, interpretative in nature, yet the results are difficult to replicate. Many similar procedures exist that apply the landscape character assessment methodology. Some of them are for expert-used only, while other ones may be participatory. Some still combine the previous approaches. Participation is beneficial, both in the assessment stage and in the judgment phase, if applicable, because negotiations prevent conflicts.

In the conducted study, a methodology for identifying LPUs has been developed and tested in a part of the Cekcyn municipality, Poland. Internally, coherent areas have been identified. They are relatively homogeneous in terms of physical–geographical, cultural, and visual features. The same principles of land management and development could be applied within them. It was considered crucial to identify a spatial pattern that people can read and imitate while shaping, planning, or managing space to protect the landscape (Bell, 2012).

The results obtained address the issues of space management in Poland, manifested by excessive dispersion of building development in rural areas, and its destructive effects on the variety and beauty of the landscape (Chmielewski et al., 2018a, 2018b; Kowalewski et al., 2013; Wilkin & Nurzyńska, 2018). Implementation of the ELC principles is regulated in Poland by the Act Amending Certain Acts in Connection with the Strengthening of Landscape Protection Tools (Sejm of the Republic of Poland, 2015), which launched the landscape audit procedure in 2019. The physiognomy examination method applied in the audit needs to be developed. Simultaneously, the landscape research conducted at Poland's local or place level fails to provide sufficient knowledge and data. The theory and tradition of landscape studies in physical geography and landscape architecture or landscape ecology remain disintegrated. For these reasons, the described above process of characterization of landscape physiognomy is aimed in the right direction. The national conditionings for the novelty of the results obtained consist in:

- Hierarchical division of landscapes to be completed at a local level, where each distinguished area represents a specific type of landscape and could be further subdivided (O'Neil et al., 1991; Swanwick, 2002);
- Recognition of the spatial pattern that represents natural, cultural, and perceptual landscape characteristics in an integrated manner;
- Entering the recognized pattern into a hierarchical and continuous landscape system.

The advantages of the LPU methodology for spatial planning may be as follows:

- Systematization of knowledge of landscape characteristics;
- Identification of landscape shaping conditions on various planning levels;
- Landscape beauty protection by imitation or restoration of the recognized spatial pattern.

Two findings confirm the ordering function of the LPU identification method. The results indicate a significant discrepancy between the zone planned in SoSDCaD and integral LPUs in the studied area. This result suggests that the method described helps identify more integral land planning zones and define management principles thereof in a more appropriate way. Moreover, the boundaries of the physical-geographical mesoregions under the classification by Solon et al. (2018) partially run through the middle of homogeneous LPUs determined during the study. The two areas prove overly divergent in the directional course in some parts, though this may also be associated with a difference in scales.

The method's limitations result from the lack of comprehensive knowledge and spatial data on cultural, historical, and natural characteristics in rural areas at the local level. A lack of data on monuments and types of plant communities has been indicated. Moreover, the adopted research area was not sufficient to fully standardize the landscapes' description. Therefore, further testing of the method in more diverse areas is needed. The general weakness of LPUs method, which paradoxically may also be seen as a strength in land use planning, results from its holistic assumptions. This refers to certain intuitiveness of spatial patterns and units or subunits boundaries. Possible conflict in planning decision-making can be minimized by participation included in the procedure in the future. However, it can already be concluded at this study stage that the identification procedure of LPUs may help implement the ELC assumptions regarding the formation of sustainable landscapes, protection, planning, and management thereof, as well as gathering knowledge on natural, cultural, and visual features of the landscape.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

Mapping Green Dublin: Co-Creating a Greener Future With Local Communities

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Abstract
Mapping Green Dublin is a transdisciplinary, collaborative action research project led by University College Dublin's School of Geography in collaboration with arts organisation Common Ground, artist Seoidín O'Sullivan, and event facilitators Connect the Dots. It took place in an inner-city neighbourhood of Dublin 8 between 2019 and 2020 and was funded by the Irish Environmental Protection Agency. This article outlines the methodological approach taken to develop a community-led greening strategy that is both inclusive and planning-policy relevant. The first phase of the project involved scientifically mapping the span and territories of trees and greenspace across Dublin 8, identifying their location and quality, greenspace deficits, and future needs. Phase two included a series of curated events from March to August 2020 to map out a proposed process for co-creating urban greening solutions focusing more on local identity and the possibilities for future creation. The scientific data was presented to communities in a way that opened up a creative and supportive space for dialogue on the wider role of trees and greening in enhancing urban resilience. Such a co-created greening plan ensures that interventions respond to neighbourhood needs, have high social and cultural value within the community, and maximise opportunities for community wellbeing. The final phase of the project identified specific areas for focused greening interventions. An important output from this action research project is a co-creation process to enable communities, local authorities, and policymakers to engage with and develop a new governance arrangement for more inclusive and appropriate urban greening strategies.

Keywords
co-creation; Dublin 8; green infrastructure; Mapping Green Dublin; urban governance; urban greenspace

Issue
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1. Introduction

The quality and resilience of ecosystems in our living environments is increasingly recognised as an important determinant of health, quality of life, and overall wellbeing. The Covid-19 pandemic and control measures, including the use of lockdowns, has foregrounded the importance and unequal distribution of good quality environments as citizens became restricted to small areas around their home and more aware of their micro-geographies. For those living in cities, and particularly in densely populated neighbourhoods, differential access to quality living and recreational space has been brought into sharp focus, raising significant social and environmental justice concerns (Kayanan et al., 2021). Deep socio-spatial inequalities in housing, health, and income are also clearly manifest in relation to the physical environment (Anguelovski et al., 2019).

The politics and politicisation of urban greenspaces (Oscilowicz et al., 2021) and particularly trees planted along streets (Carmichael & McDonough, 2018; Rotherham & Flinders, 2019) in cities across the globe points to the need for a new direction towards more just green strategy-making for urban neighbourhoods. The expanding sphere of the environmental justice debate to climate change (Schlosberg, 2013) incorporates recent critiques of green and eco-gentrification. Internationally, many high-profile parks and green public attractions have been criticised for their inequality of access and gentrification effects (Anguelovski et al., 2020; Oscilowicz et al., 2021). Green gentrification is complex, driven in part by economic development and place-making strategies that aim to attract newcomers to particular, often disadvantaged, urban areas but it can also emerge as an unintended consequence of broader climate mitigation and biodiversity strategies. To develop more inclusive and sustainable cities, deeper dialogue and mapping are required to unearth local concerns, histories, and vulnerabilities, and generate appropriate place-based responses (Bodenhamer et al., 2015; Roberts, 2016). This kind of approach would acknowledge that urban processes, such as greening, do not happen in a vacuum but within particular spatial and socio-cultural contexts that can and should be made legible. The social reality for communities impacted by new forms of socio-spatial restructuring needs to be made visible and discussed to clear the way for new approaches, ideas, and action. Co-creation approaches that highlight the greening issues that most affect individual and collective's wellbeing and quality of life, as well as supporting the development of new and the privileging of alternate knowledges can address some of the critiques noted above and build more inclusive engagement.

This article outlines Mapping Green Dublin (MGD), a 24-month project in Dublin, Ireland, that adopted a co-creation approach—between scholars, activists, artists, other formal stakeholders, and residential communities—to develop a neighbourhood greening strategy from the bottom-up, build a community coalition for action, demonstrate to policymakers the value of adopting a community based approach to green strategy making, and feed into the range of plans and policies currently under review and development in the city. Drawing on the work of Mouffe (2007), we aspired to explore how community activism—employing arts-based practices—can play a critical role in subverting the dominant planning hegemony—rigid, neoliberal, and developer driven—and contribute to the construction of new ideas and subjectivities that provide a platform for change. Empowering communities to access, understand, and deploy scientific data to expose deficits, recognise strengths, and advocate for more equal access to greenspace and a high-quality physical environment is highly political but important in developing more inclusive, diverse, and sustainable cities. Through MGD, we developed an approach grounded in iterative dialogue, open creation of, and access to scientific data, as well as arts-based methods and practices. This enabled deeper understanding of the everyday impacts of urban dynamics, particularly in neighbourhoods undergoing rapid socio-spatial transformation; validated more inclusive knowledges and ways of knowing; and, ultimately, ensured that greening interventions are born from and respond to genuine neighbourhood needs. The article situates the project within the burgeoning literature on co-creation in planning and focuses on how new urban actor constellations can support social and environmental justice through more place-based and grounded strategy development and implementation.

2. Co-Creation and Urban Greening

Co-creation has become increasingly popular in recent years as a concept, method, and policy tool (Steinhaus et al., 2018), and the associated co-production of knowledge is seen as an approach for the development of inclusive policy and practice. This has been increasingly applied to the development of policy for the delivery of public goods linked to health, education, community services, and planning (e.g., Alford, 2009; Donetto et al., 2015). Such terms are perhaps the most recent iteration of collaborative planning (Healey, 1997) or communicative planning (Innes, 1998), approaches that focus on the social construction of planning and its role in developing shared meaning between different stakeholders. Drawing on Giddens' (1984) structuration theory, collaborative planning is concerned with not just the interplay of different actors in the urban system but with how these interactions are structured by broader institutional designs, values, and systems (Healey, 2003). In a broadly neoliberal political-economic system, institutional designs, what becomes valued, and what is made possible in the urban arena are shaped to a large extent by market forces and the need to accommodate, or at least not antagonise, powerful development actors. Collaborative approaches thus emerge to try to mediate between different perspectives to come to a shared view and create the conditions under which transformative practices can potentially emerge. Understood within this broader framing, co-creation can be understood as a method or tool that enables collaborative planning practices and the development of shared meaning by working towards consensus building. It has the potential to remove the boundaries between experts and citizens and to reconfigure participatory placemaking (Ermacora & Bullivant, 2016) as a means to achieving more just outcomes.

The growing utilisation and appropriation of co-creation processes in particular has been critiqued by Horvath and Carpenter (2020) who argue that rather than challenging, they can enable co-option by the state. Critiques of contemporary participatory methodologies (Cooke & Kothari, 2001) and state-led community engagement practices (Fawcett & Marsh, 2014; Flinders & Wood, 2014) abound and most focus on the idea that they exist to neutralise dissent through depoliticisation. In some cases, the public engagement activity is outsourced, creating a new role for private consultants in managing public participation and engagement (Brudell, 2014). Acknowledging these critiques, we argue for a conceptualisation of co-creation that is radically different. Rather than striving for consensus, we propose a co-creation approach that surfaces, acknowledges, and highlights conflict, dissent, and injustices as an important first and necessary step to enable meaningful interactions and forward thinking. This approach may overcome the "mismatches" that occur in participatory planning (Abram, 2011, p. 122) such as that between the public as an idealised, abstract political construct (for the purposes of thinking about how the state works) resulting in well-informed, active, and critical individuals being "worked around" and feeling unheard. Such an idealised notion of the public is also at odds with the deep historical social relations, which are already in place, and the everyday lives of people. Abram (2011) calls for a greater understanding of two models of democracy in planning: an abstract democracy whose public elect representatives but may also sometimes participate directly in certain activities, and inspiring and often distinctive participative actions, where certain people and personalities come together to reach unique outcomes. A more just co-creation process would problematise these two approaches and creatively work through these spaces of engagement.

Co-creation is also seen as a tool of the creative economy, involving art and design-based practices in dealing with big societal changes such as urban regeneration and the transition towards a low carbon economy. This may be seen within a longer history of the arts being given a key role in cultural branding dealing with urban problems, and the need to adopt a culturally informed perspective in urban planning (Florida, 2002; Landry & Bianchini, 1995). Lees and Melhuish (2015) have critiqued the lack of depth of the social impact of such processes, and the lack of consideration for the problems associated with gentrification and displacement that may come with a culturally informed perspective, citing an unspoken expectation for arts and culture to be uncritical or "minimum risk" (Phillips, 1988/2000, p. 100). Mouffe (2007, p. 5) asserts that artistic activism can play a critical role in processes of urban and social justice by subverting the dominant hegemony and contributing to the construction of new subjectivities. Within urban communities, arts organisations often work within spaces of progressive struggle where culture is a critical and crucial component of everyday life (Yúdice, 2003). Through their role as mediators and their practices, groups that are often most disenfranchised or absent from deliberations can be supported and brought in as a way of progressing towards social emancipation, liberation, and activation (de Sousa Santos, 2014).

Across Europe, an array of local governance arrangements—broadly defined as all formal and informal political institutions, processes, and practices involving state and non-state actors—is being experimented with to bridge ecological sustainability and urban social justice (Cook & McGinn, 2021a) imperatives and shift towards more just and inclusive urban places. For example, the European funded UrbanA project (www.urban-arena.eu) highlights the role of particular individuals or dedicated organisations in systematically connecting actors of different perspectives and acting as intermediaries who can translate between groups' different discourses and rationalities. These can take a variety of formats including working groups within municipalities, private companies, or civil society (Cook & McGinn, 2021b). A key lesson from their work is that situated or place-based governance interventions should make space for adaptation, experimentation, and meaningful participation, and tap into existing community networks to create new actor constellations before reaching out to state or other actors. Similarly, Lund (2018, p. 5) highlights the importance of creating mechanisms for "*citizens themselves* [to] invent or articulate new services or products of public value and new ideas about which institutional structures may support such activities," and argues for co-creation processes that move beyond the engagement of professional citizens to adopt more creative and inclusive forms of civic engagement.

Despite the potential positive impacts, realising the potential of such actor constellations in support of social and environmental justice is challenged by the broader political-economic environment. In recent decades, the commodification and financialisation of urban property, land, and spaces has intensified inequality and development pressures being felt by grassroots groups. Recognising the drivers of urban socio-spatial injustices such as neoliberal growth, austerity urbanism, and uneven environmental health and pollution patterns is a significant and vital first step in identifying the barriers to inclusive greening policies and practices. Progress involves challenging the claim that urban greening is a public good for all (Agyeman, 2013; Anguelovski et al., 2020) particularly in a rapidly developing urban context. The business-investor-led imaginary for urban spaces (Amin, 2013; Harvey, 1989; Swyngedouw et al., 2002) and associated assumptions about particular aesthetics can have profound negative implications for inclusion and justice (Lawton, 2019). When a new place-identity, amenity, or infrastructure are driven by city-branding imperatives and policies (Cook, 2008; McCann & Ward, 2012), the outcome is usually a city that prioritises consumption and investment returns and where everyday lives and activities are of lesser significance. The right to a good quality and fair everyday life for residents and workers cannot be realised only through top-down political imperatives but neither can they simply be a matter of subaltern resistance and social organisation against the state (Datta, 2013). Bringing these two approaches into productive dialogue is critical to realising meaningful and inclusive urban development. The imperative to ensure that greening deficits in urban neighbourhoods are acknowledged, identified, and addressed has never been stronger. However, this process can be highly emotive and sensitive.

In its most radical form, co-creation approaches would be highly disruptive to existing hierarchical power relations. Drawing on Horvath and Carpenter (2020, p. 22), we acknowledge the importance of cognitive justice—recognising and valuing the co-existence of different forms of knowledge in the co-creation process and the need to develop methodologies that can capture these diverse knowledges from a broad cross-section of individuals and groups. The foregrounding of alternative knowledges disrupts long-standing structural and other power dynamics and is a core element in literatures on de-colonisation and indigenisation in geography. These argue that dominant narratives close down possibilities for thinking and action and that place-based practices should be brought front and centre in debate and practice. However, few examples currently exist of the successful translation and grounding of the principles of such place-based co-creation into an active policy environment for greener, more sustainable, and just urban environments. Paying attention to the broader structural dynamics shaping neighbourhood development trajectories and the inclusion of different sets of actors produces a unique approach to co-creation that is about listening and expanding rather than listening and pushing for consensus. Expansive and open co-creation processes can help to de-mystify the language, policies, and magic of planning policy and practice (Abram, 2011, p. 19), and equip the community with the data and cognitive tools to develop proposals that feed into and have legitimacy within policy-making circles and processes.

We therefore argue for an understanding of co-creation as neither top-down nor bottom-up, but critically and expansively working through the space between policy makers/practitioners and public knowledges and discourses of greening. Through the adoption of a place-based approach to the governance of urban greening that accepts all parties are equal but that different knowledge producers hold different sets of expertise, vertical relationships between researchers/researched and policy makers/practitioners and communities can be transformed and solutions can grow from place.

3. The Dublin Context

Since the introduction of the first targeted regeneration schemes in Dublin in the late early 1990s, former industrial and working-class residential parts of the south-west inner city among other places have been under significant (re)development pressure (Kelly, 2014). The Dublin 8 district, traditionally a relatively low-income, inner-city working-class neighbourhood, provided the spatial context for the MGD project and is an area that has been subject to repeated rounds of policy intervention for more than 25 years (Moore-Cherry et al., 2015). Although some of the most disadvantaged and large-scale public housing complexes in the city are located in the area, the most significant investments have included the establishment of a cluster of technology start-up companies (the Digital Hub), tourist infrastructure, such as the Guinness Storehouse, and the construction of a new National Children's Hospital. Dublin 8 is increasingly polarised between long-term residents who have experienced sustained disinvestment and the new residential and business gentrifiers. Recent developments have transformed the socio-economic make-up of Dublin 8. By comparison to other areas of Dublin, the area is densely occupied and the composition is dominated by young adults (20–30s) with few children, many of whom live in apartments and are renters (Central Statistics Office, 2016). There are also remnants of old Dublin that include older housing stock in the form of terraced single-family homes and residents that have lived in the area often for many generations. The area is occupied both day and night by workers and residents and carries a heavy traffic burden, particularly to the west side of the study area which is a major traffic artery from the suburbs into the city centre. At present, it is experiencing development pressure as large unused industrial sites (such as Bailey Gibson and Player Wills) are being re-purposed for multi-storey mixed-use buildings. Build to rent and co-living housing developments of significant height and scale, some up to 19 storeys in a traditional two to three storey environments, by international investment companies, do little to address the housing crisis and aggravates what is an already intense politics of housing in the area (Kelly, 2014; Punch, 2014).

At the same time as access to affordable housing and security of tenure is increasingly politicised, in recent years, the attention of the local authority has moved to place-making. This is partly a response to academic and community critiques of the nature of past development that has resulted in a poor quality, exclusionary public realm in the city (Moore, 2008; Van Melik & Lawton, 2011), as well as a response to more general trends in urban design and planning where urban attractiveness is considered a critical enabler of economic development (Lawton, 2017; Musterd & Kovács, 2013) and the role of the arts has become an important part of austerity urbanism (Grodach, 2017). The 2015 Liberties Greening Strategy (Dublin City Council [DCC], 2015) has served as a guiding tool to improve accessibility and the quality of existing green spaces, as well as supporting the creation of some new ones in the eastern part of our study area. But in other parts of Dublin 8, there are ongoing local concerns about the visible appearance of the area, the lack of greenspace, persistent intergenerational social problems, and a sense of being left behind (South Inner-City Community Development Association, 2019). Our research suggests that the provision of greenspace per person in the area is approximately 10 m^2, the absolute minimum advised by the World Health Organisation (International Society of City and Regional Planners, 2009) and less than half the European average. Despite the formal creation of spaces such as Weaver Park, simultaneously, more informal community greenspaces are being squeezed out. Given the extreme housing crisis, arguments frequently pitch the need for housing against the retention of greenspaces, particularly those that are small-scale and community-based. Where particular forms of greenspace, often heavily surveilled, are provided in areas undergoing gentrification, they can serve to further marginalise under-privileged communities (Cole et al., 2019). Triguero-Mas et al. (2021, p. 6) have suggested that, while well intentioned, the Liberties Greening Strategy in Dublin 8 has had similar effects with one planner recognising the need for more "political analysis of how green space could go towards remedying… social issues." It is within this place-based context that the MGD partnership emerged to seek a new approach to greening strategy-making.

4. Mapping Green Dublin

MGD began as a broader call for research under the theme "Greening Dublin's Inner City" funded by the Irish Environmental Protection Agency. The call focused on identifying ways to foster increased community engagement with Green Infrastructure (GI) in the urban environment.

4.1. Creating the Partnership

The MGD project team comprises UCD's School of Geography, Common Ground arts organisation, Seoidín O'Sullivan (independent artist), and Connect the Dots, bringing together the scientific and technical expertise of geographers with a range of other groups and organisations. The academic team included colleagues with extensive expertise in urban GI and a significant track record in mapping and analysing the trees across Dublin city and the surrounding local authority areas. Another academic colleague had extensive experience working on urban governance and had built up productive relationships with artists and social entrepreneurs over a period of more than five years through a previous temporary urbanism project, Granby Park (Moore-Cherry, 2017), and engagement with the not-for-profit A Playful City (Moore-Cherry et al., 2019). Seoidín O'Sullivan had previously engaged with the School of Geography team on the Tree Line and Hard Graft projects—a critical feminist and socially engaged practice of care, exploring the urban commons by collectively grafting, and planting orchards (www.seoidinosullivan.com). During the period when the MGD project proposal was being written, the Hard Graft project was being hosted at Common Ground, an arts organisation based in Dublin 8 that focuses on how the arts can be used politically to view and alter the circumstances in which people live. A track record of network building by the scientific team across the arts, community, and social enterprise sectors for over more than five years was therefore drawn upon for the project.

As a long-standing place-based entity, the Common Ground organisation emerged as critical to the success of the project. Through experience of over a 25-year period in the area, Common Ground have acknowledged how cultural branding can gloss over tensions in contemporary society stating that "whilst consensus forming brands may have a place in the creative economy, in the visual arts, and the community development sector, there is a much deeper alignment with disagreement, dissent, and critique" (Common Ground, 2019, p. 6). Common Ground (www.comonground.ie) sees art as a powerful means of viewing and altering the circumstances in which people live. The creative knowledge practices they support often focus on marginality and critical ecology, making present creative and critical knowledges and ways of knowing that often remain largely unrecognised by the dominant epistemologies of urban planning (de Sousa Santos, 2018, p. 2). Co-creation is a complex and messy process. Drawing out alternative ways of knowing relies significantly on access to a range of stakeholders and trust between them. The long-term advocacy and legitimacy of Common Ground as an organisation grounded in the principles of social and environmental justice helped the project team to identify key stakeholders and also provided rapid access to a wide range of community groups and activists. The independent artist supported by Common Ground also played an important bridging role between the academic members of the team and local residents based on her previous work within the neighbourhood. She also brought expertise in critical and socially engaged arts techniques to the anticipated co-creation process while Connect the Dots brought their wider policy networks and design expertise to the team. MGD was therefore developed and positioned as a collaborative action research project comprised of cartographers, geographers, artists, designers, activists, and residents working together to identify challenges with and propose new ideas for GI in an inner-city neighbourhood.

4.2. Actioning the Partnership

MGD was undertaken in three distinct stages (Figure 1), each with its own distinct methodology:

a. Mapping trees: This phase involved digitising Dublin's urban forest, assessing its geographic distribution, and evaluating the associated ecosystem services. This work was completed for the entire DCC area and then in more detail for the Dublin 8 study area;
b. Co-creation: This involved creative participatory deep mapping techniques, critical art engagement practices, and online survey questionnaires to gather community greening recommendations;
c. Action: This used design thinking methods to develop an urban prototyping workshop with members of the community in the area to support them in developing their own greening projects. Qualitative interview techniques were deployed to elicit a policy/practitioner response

Figure 1. MGD project structure.

to the community recommendations from the co-creation stage. A community-based urban greening strategy was created and included a set of pathways to enhanced greening at neighbourhood level.

4.2.1. Stage One: Data Mapping

Information on green cover is available for cities in Europe (Urban Atlas, https://land.copernicus.eu/local/urban-atlas), including Dublin. These data show relatively large open green areas (minimum mapping unit of 500 m^2, with a minimum mapping width of 10 m) across the metropolitan area. These data are suitable for large-scale urban planning but are of limited value at neighbourhood scales where much of the green cover exists in the form of small parks, private gardens, and cemeteries. Moreover, there is no detailed mapping of trees which form an important component of the GI in urban areas. The MGD project undertook to map the trees in the DCC area to complement existing information on public green areas. These data were needed to evaluate relative provision of GI in different neighbourhoods and provide a context for assessing the Dublin 8 study area. A variety of datasets were employed to map the GI across the DCC area, analyse geographic patterns, identify areas of deficit, and evaluate ecosystem services (Table 1). These datasets can be categorised into those directly associated with GI (green cover and trees) and those that provide physical (e.g., rivers and roads networks), environmental (e.g., traffic), and socio-demographic (2016 household and workplace censuses) contexts.

A critical part of the MGD project was the generation of GI information that supported the co-creation process. Much of this was provided in the form of maps and tables that showed the uneven distribution of trees and parks across the city (Figure 2) and compared the study area (Dublin 8, outlined in black) with the surrounding city. Initially, simple counts of trees by height were calculated for public parks, along roads, within private domestic gardens, and within large private spaces (school grounds, golf courses, etc.). Subsequently, tree coverage and open green spaces across the urban landscape were evaluated with comparison to the distribution of daytime and night-time population. All of the geographic data were integrated using a spatial grid (with a resolution of 200 x 200 m or four ha). Population data for census' areas, green land-cover, tree location data, and road traffic data were reconfigured with ArcView GIS to create a consistent spatial framework. The Dublin 8 case study neighbourhood spans an area of very low to moderate tree cover. The scientific data produced by the team thus cor-

Table 1. A list of the main sources of information used in the MGD project.

Data	Source	Content
Prime2 OSi dataset	Ordnance Survey Ireland	Vector data: roads, building footprints, parks, and water.
2016 household and workplace censuses	Central Statistics Office for workplace zones.	Residential population data for small areas and work population
Dublin city traffic	Traffic Department SCATS System	Traffic count by hour along sections of the road network.
Aerial image	BlueSky (July 2018)	High resolution (12 cm) data (red, green, blue, and near infrared).
Digital elevation model	BlueSky	High resolution (1 m) Lidar data
Tree information	Fieldwork and crowd-sourced data	Tree dimensions (height and diameter at breast height) and species.

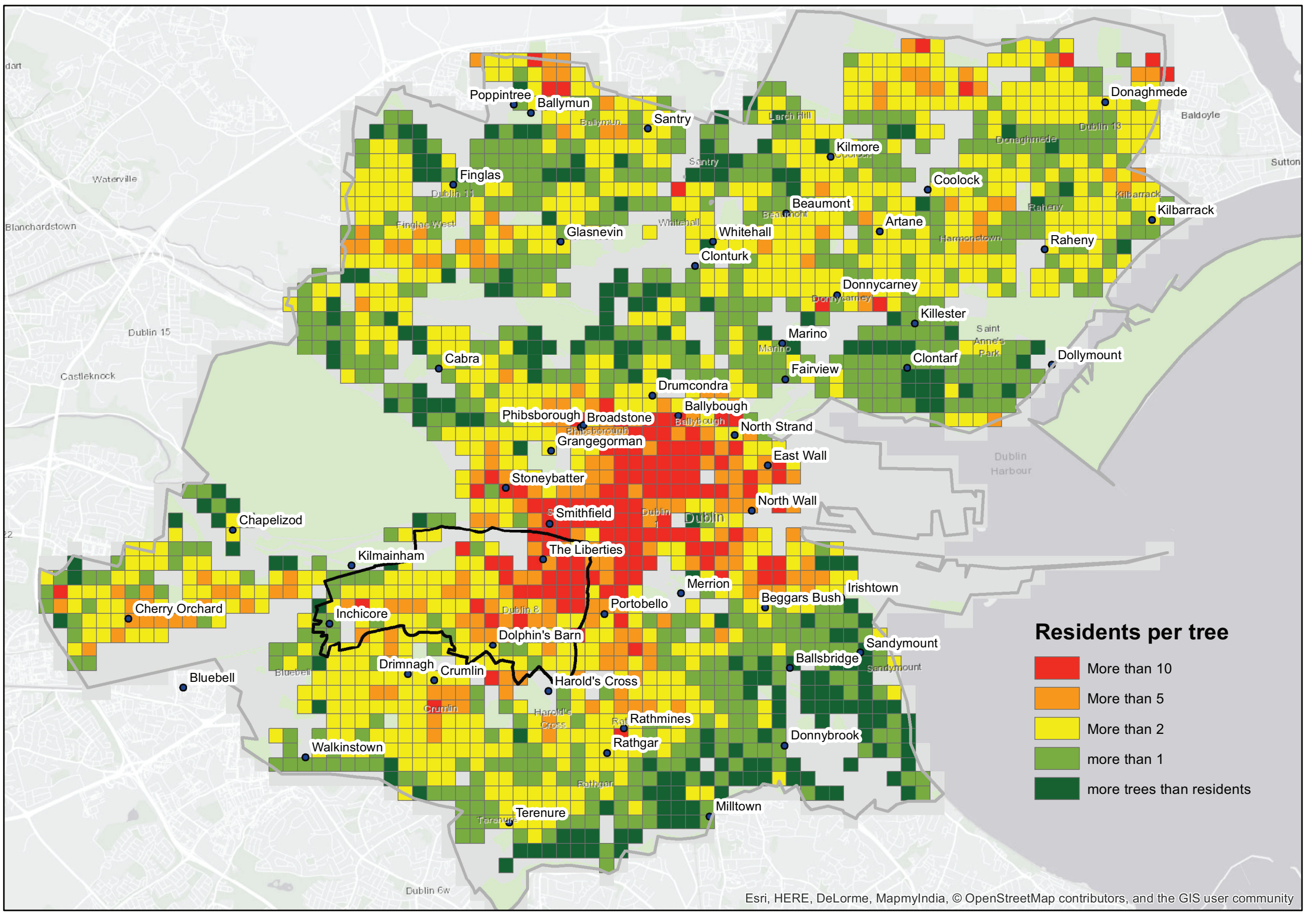


Figure 2. The ratio of trees to residents for populated areas of DCC (residential populations over 100).

related with the lived experience of residents in the area and provided the evidence for them to begin to formally articulate—what until this point had been perceived—neighbourhood deficits.

A simple urban ranking was developed by combining data on population density, tree coverage, and traffic intensity. High rank is associated with high population, high traffic flow, and low tree count, and Dublin 8 scores very highly on all of these measures (Table 2). Through this exercise across the city of Dublin, the study area of Dublin 8 was defined as being comparatively underserved in terms of GI. To measure the quality of the urban environment overall, traffic data were used to estimate carbon emission (based on vehicle number and road lengths) and tree data were used to estimate carbon sequestration. The data for the Dublin 8 study area indicate relatively low storage and high emissions, when compared to other neighbourhoods, indicating that air quality is also likely to be relatively poorer in this part of the city.

Engagement with the tree and greenspace data for the entire city and more focused analysis of the study area provided both a greening context and an evidence base to articulate greening inequalities. Maps generated as part of the scientific analysis were made available online and presented at community events. The project team responded to requests from the community at these events for further mapping (e.g., pollution/traffic maps, maps of tree species and carbon sequestration, maps of public land and access, and maps of vacant spaces) as the community became more engaged with the environmental issues and the relative impoverishment of GI in their neighbourhood. In this way, the mapping process was iterative in nature, aiming to inform and make scientific data openly accessible, but also was deliberately political to level the playing field between

Table 2. Statistics informing neighbourhood ranking of Dublin 8.

Measure	Dublin 8	Surrounding built up area
Population density (persons per ha)	894	628
Tree density (trees per ha)	200	273
Average hourly traffic (vehicles)	295	191

the residential community and traditional gatekeepers of data in the city.

4.2.2. Stage Two: Co-Creation

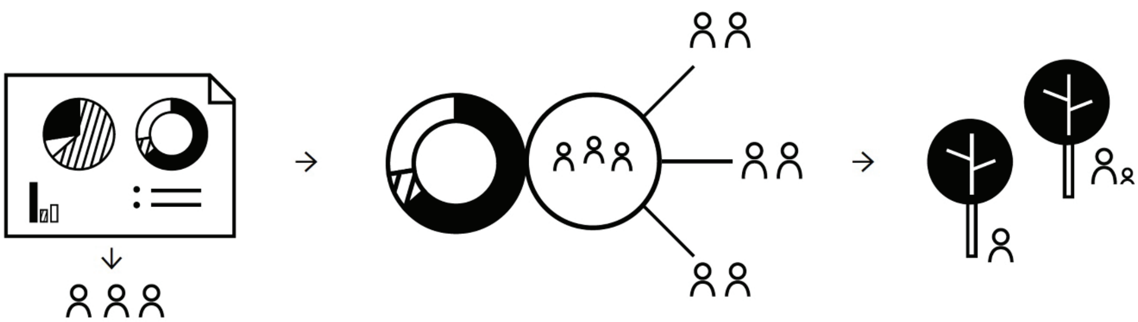
The adoption of a community-led co-creation approach to the development of the greening strategy was a conscious and political choice. A number of co-design projects for greening are underway in Dublin at present, but the philosophy of MGD was that the project should be led by community needs and ideas. Hence, developing a process for community engagement became as significant as the final product.

Because of the nature and membership of our project partnership, the MGD co-creation process deliberately aspired to develop alternative ways to listen to community voices and involve them in generating shared understandings of their neighbourhoods and injustices (Horvath & Carpenter, 2020). Based on the principles of co-creation and tools of both urban social listening (Hollander et al., 2016) and political listening (Brickford, 1996), we designed a co-creation process that had three distinct phases (Figure 3).

The process of listening, expanding, and grounding was developed through a series of activities (Table 3) over a 12-month period for this project. At the heart of the approach was generating new interactions between partners based on dialogue, creating new links (between researchers, researched, artists, and designers), and providing a safe environment for deliberative knowledge production. It was an arena of diverse and at times conflicting interests in that, at different times, co-creation partners had different ideas about the overall narrative to be developed. The co-creation process required time, patience, and sensitivity to all partners and the context of this particular place, necessitating a role for a key bridging individual within the project team.

During the focus groups (listening phase), a range of greening deficits were identified by participants. Clearly defined areas for improvement and areas with strong greening/ecological value for the community were also acknowledged. The key issues to emerge related to inappropriate type/form of greening, greening types being pitted against each other, care and maintenance, urban development pressures, governance of greenspace, and a challenging socio-cultural context for greening. This work informed the planning and preparation for the second event, the community launch.

The community launch event—an all-day open mapping workshop held in a local educational facility—was attended by 80 participants. Large maps detailing roads, landmarks, and all the trees in the area were made available and participants were invited to use stickers to indicate areas of strength (green), potential (yellow), and areas of deficit (red) for up to nine dimensions of greening (trees, greenspace, biodiversity, play, sport, seating, walking, cycling, cars/pollution) that emerged from the earlier deep mapping focus groups. A total of



Present data · Listen and Expand · Re-ground

Figure 3. Phases of the co-creation process.

Table 3. MGD co-creation activities and timeline.

Activity	Purpose	Timing
Focus groups	Deep mapping.	Autumn 2019
Community launch event	Presenting data and maps and gathering diverse insights in an open way.	March 2020
PLOTS tool	Exploring the micro-geographies of the neighbourhood during the Covid-19 lockdown.	Summer 2020
Camac River Walk	Camac go-along using Ubipix technology and GIS story-mapping techniques exploring lack of access and experiences of the river.	Summer 2020
Urban proto-typing workshop	Using design thinking to proto-type and develop projects for action.	August 2020

155 comments were received and mapped geographically. During the workshop, Seoidín O'Sullivan ran a family-friendly event to map out emotional responses to particular trees. Maps developed during the participatory mapping event were also made available on the website and on social media and used to elicit further responses from the community using an online survey (N = 170). The nine interconnected dimensions of greening were synthesised under three main axes:

- Green environment (trees, greenspace, and biodiversity);
- Green amenity (play, sports, and seating/ benches);
- Green mobility (walking, cycling, and cars/ pollution).

A comprehensive set of recommendations (N = 160) was compiled from contributions made during the focus group event, individual comments made at the community launch and lunch dialogue workshop, and the comments received from the online community survey. Three synthesis maps and charts detailing the geographical locations and nature of these recommendations were created (see www.mappinggreendublin.com).

Due to Covid-19 lockdowns, alternative strategies were adopted to maximise engagement and the harnessing of local knowledge. In July 2020, the PLOTS tool was created by artist Seoidín O'Sullivan, and the community were invited using the My Map App or by hand-drawing to examine and map their individual micro-geographies and the experience of local outdoor space during lockdown. Through this critical mapping of micro-geographies, individuals commented on the changing local environment during lockdown, noticing reduced pollution, and the nature and quality (or lack thereof) of greenspace closest in (Browne, 2020; Rich, 1986) to their bodies and homes. When restrictions were lifted a group of individuals were taken on a critical mapping and walking exercise along the river Camac to highlight the lack of access along a large proportion of the riverside. A survey questionnaire and video technology (Ubipix) were utilised to gather visual and qualitative data from the walk and the data gathered was inputted into GIS story mapping software.

The final stage of the co-creation process overlapping with the action phase was the urban proto-typing workshop. In our study context, urban prototyping involved the framing, brainstorming, drawing out, designing, testing, and refining of ideas relating to the urban environment. This was attended by members of the neighbourhood greening forum, one of the key outputs of the project.

4.2.3. Stage Three: Action

Given the emphasis in MGD on community empowerment and leadership, an important action identified during the focus groups was the establishment of a neighbourhood greening forum. At our community launch event, 35 participants initially expressed interest and 13 became actively engaged. Members of the forum developed greening ideas anew or further developed and refined pre-existing ideas. The MGD team supported participants to develop their project ideas through design thinking methods at an outdoors urban prototyping workshop (Schiffer & Clavin, 2020) in August 2020. Landscape architects, architects, an ecologist, and a city planner were invited to support community members to progress their thinking and leverage relationships with other stakeholders that could help convert project ideas into action. An urban proto-typing toolkit was developed as part of the action and is available on our project website (http://bit.ly/Urbanproto-typing) for widespread use.

Similar to the discussion in Cook and McGinn (2021b), our action phase also focused on building bridges beyond the community as a way to leverage support for the project goals beyond the project funding timeline. Qualitative semi-structured interviews were undertaken with key policymakers, practitioners, and landholders where the community recommendations arising from the co-creation stage and projects proposed by members of the greening forum were presented (Table 4). Following the urban proto-typing workshop and discussions within the forum, the rationale, approach, the desired outcome of each project, and the synergies between them had become much clearer. Three categories were developed, which could aid in identifying key audiences for the project and stakeholders.

To progress these projects, the MGD team opened up conversations with major landholders in the area such as the new National Children's Hospital and Digital Hub, presenting both scientific data but also alternate and local knowledges, in an attempt to build support and access space for the community proposals. From these engagements, barriers and opportunities to realising community desires were identified and policy recommendations in support of community-led greening were developed. As the key output, the community-led greening strategy (https://bit.ly/Communitygreeningstrategy) identifies eight pathways to change and meaningful action on greening. Through combining the community and policy insights, a set of actions to enhance and inform the provision, quality, use, and maintenance of green social infrastructure in Dublin 8 and beyond were identified. Thirteen actions, representing a greening agenda for the area, are the culmination of a co-creation process that is neither solely bottom-up or top-down, but rather works through different scales, knowledges, and practices.

5. Sustaining Momentum

Although the MGD project was time-limited, there was a desire by all involved that the approach and strategy would have longevity beyond the 24 months. A key part of the philosophy was not to present data regarding

Table 4. Proposed projects developed by members of neighbourhood greening forum.

Project type	Project
Intergenerational greenspaces	• Community garden (Inchicore) • Turvey Park sensory garden • Greenspace improvement on Devoy Road • Intergenerational private gardens • The Dublin 8 bench project
Canal and walkway activity	• FUNAFLOAT: Water-based activity for young people along the Grand canal • Grand Canal Towpath from Sally's Bridge to Drimnagh Luas stop • A pilgrim path, Camino: A walkway in Dublin 8
Small projects with a big impact	• Parklets • Pocket forests (www.pocketforests.ie)

greening deficits, study the community, and then withdraw fully, but to ensure that an infrastructure was left in place to support ongoing engagement of the community with urban greening. MGD developed a particular type of local governance arrangement—the greening forum—which is grounded in and supported by scientific evidence, is strategic in nature, but is also transformative and dynamic in its thinking and actions. The group is open. Members consist of those who have already been involved in planning consultations, are known to the council and other landholding bodies, may have gone against plans and proposals and felt unheard (Abram, 2011), and also those who would not usually participate in public consultations or be involved in local groups. The actions of the forum are built on the deficits, potential, and opportunities identified through scientific and community mapping drawn out both from spatial analysis as well as through arts-based, creative practices. The forum is strategic as it is a recognisable structure where community members support one another, learn from the experiences of others, and from which they can engage more formally with landholders, policymakers, and others. It is transformative as it has used scientific data to engage with local decision-makers and successfully make the case to access space and develop projects on the ground, such as a well-used sensory garden developed at Turvey Park in the Summer of 2020, which is continuing to build momentum, and at least two pocket forests (a method of planting small biodiverse forests in urban areas) in the area. The greening forum operates informally on a number of different levels with the focus on action: often at small scales (e.g., planting of public spaces, activating blue spaces, and planting trees in gardens), knowledge sharing (online/offline), and with the ongoing support from both a community partner (Common Ground) engaged in critical and socially engaged creative practices and a local authority (Biodiversity Officer at DCC) that can lever relationships and action. This longer-term partnership structure should ensure that the group is included in state and municipality-led greening plans and initiatives, whilst also remaining embedded within local communities, and has access to a wider network of landowning stakeholders, NGOs, and academic institutions.

The development of a community greening forum is one way to ensure any greening plans are locally relevant, respond appropriately to community needs and are grounded in community action and empowerment. Supported by Common Ground going forward, the group can be part of a creative and inclusive form of civic engagement (Lund, 2018). However, the time investment required in adopting this approach to greening is significant and the skills required are often unavailable within the local government and planning structure. One critique of the project might be that through the production of a high-quality community-led greening strategy, community expectations are raised unrealistically. However, we would argue that our approach puts community empowerment front and centre. MGD was not about co-designing a wish list that cannot be fulfilled by local authorities, nor co-producing a particular output, but rather about co-creating a deliberative process through which communities can be empowered to engage for themselves. A central aspect of our community recommendations and the policymakers' reflections are that the governance of greening within the city is very fragmented and weak. There is therefore an imperative to consider alternative approaches to greening and the new urban actor constellations created through the MGD project. The 13 actions recommended may provide a pathway forward. This will require significant re-thinking of current structures and practices of greening and the development of much higher levels of trust between key decisionmakers and the local community. The disruption of binary roles and unequal power relations of expert/non-expert, researcher/researched, and local/outsider were transcended during the process through practising positionality and reflexivity (Schiffer, 2020). Whether this can be sustained and generate new systemic approaches is too early to say. What is clear is that the development of the strategy document is already having impact. The local authority is currently reviewing the City Development Plan and local councillors are advocating for the inclusion of some of our actions as strategic objectives within the new draft plan. The landscape architects within the city council are also currently revising the Liberties Greening Strategy and leaning heavily on our community greening strategy—particularly the scientific evidence base—for direction and ideas. Empowering communities with a strong scientific evidence base and the skills to engage with professionals in their language and through tools they recognise might therefore represent a new way for communities to participate and engage in local planning more effectively. Whether the contents of the greening strategy itself and the greening forum are compatible with future desires and aims of public consultation as carried out by the local authority and other bodies is still yet to be fully tested.

6. Conclusion

The co-creation process practiced was rich, deep, iterative, and also fruitfully messy and time-consuming. It began as a collaboration between academics, artists, activists, and designers and culminated with a wider community of residents, policy makers, practitioners, and interested individuals. Rather than viewing the co-creation process as a panacea for the ongoing issues around engagement in planning and design processes, it can add value to other critical practices and research approaches. The key outcomes—the strategy itself and the greening forum—are a lasting legacy. The strategy provides an evidence base for greening deficits and for what the community wants, and the greening forum provides a space for those who are active but may have felt unheard in previous consultations, plus those who do not usually engage. The new actor constellations produced work through top-down and bottom-up processes and aim to critically and creatively work through the space between a more abstract model of participatory or collaborative planning, and the inspiring but specific ad-hoc actions that usually arise from certain specific people and personalities. The initiatives created by members of the forum are ongoing, address neighbourhood need, and inspire action into the future. The model for the forum ensures that the group is open to new members and supported by appropriate expertise and encouraged to be creative in developing and experimenting with new ideas and practices for a more resilient community.

International debates on resilient and sustainable communities and active citizenship have been magnified during this project and particularly due to the Covid-19 pandemic. The importance of trees and greenspace nearest to residences for physical and mental health and wellbeing has become more evident during public health mobility restrictions. Despite this evidence, greening is still often an after-thought within a developer-led planning system, as exemplified in Dublin, and there is still a heavy reliance on ad-hoc greening initiatives with an idealised notion of the public and how public engagement can occur with a top-down approach. A more significant contribution from local greening fora is the missing link in ensuring communities can articulate their greening needs and that greening plans are appropriate and optimise impact. This however requires significant time investment by all parties, a recognition that trust-building is a slow process, and a willingness to disrupt traditional dynamics and engage in new ways of working. This is particularly the case in historically disadvantaged communities where there has been a history of fraught dynamics with, for example, local authorities and a feeling that an area is under constant development pressure. Academics, artists, and place-based community organisations can become critical supporters and interlocutors empowering groups through access to science, responding to community needs and then later bridging out to other stakeholders. These new actor constellations open up dynamic new spaces of urban governance and action that are critical to achieving more inclusive, just, and sustainable cities.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

A Community of Practice Approach to Planning Water Sensitive Cities in South Africa

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Abstract
As South African cities urbanise alongside climate change, resource constraints, and socio-economic challenges, water sensitive (urban) design (WSD) is slowly gaining traction as a framework to address water security goals and entrench resilience. This article reflects on the progression of WSD in South Africa and discusses the broadening of its initial association with stormwater and physical infrastructure to include critical governance and institutional arrangements and social engagements at the core of a water sensitive transition. The approach is being adapted for the socio-economic challenges particular to South Africa, including basic urban water and sanitation service provision, WSD related skills shortages, a lack of spatial planning support for WSD, and the need for enabling policy. Since 2014, a national WSD Community of Practice (CoP) has been a key driver in entrenching and advancing this approach and ensuring that the necessary stakeholders are involved and sufficiently skilled. The WSD CoP is aimed at promoting an integrative approach to planning water sensitive cities, bridging the gaps between theory and practice and blending the social and physical sciences and silo divisions within local municipalities. Three South African examples are presented to illustrate the role of a CoP approach with social learning aspects that support WSD : (1) the "Pathways to water resilient South African cities" interdisciplinary project which shows the institutional (policy) foundation for the integration of WSD into city water planning and management processes; (2) the Sustainable Drainage Systems training programme in the province of Gauteng which demonstrates a skills audit and training initiative as part of an intergovernmental skills development programme with academic partners; and (3) a working group that is being established between the Institute for Landscape Architecture in South Africa and the South African Institution of Civil Engineering which illustrates the challenges and efforts of key professions working together to build WSD capacity.

Keywords
community of practice; South Africa; urban water resilience; water sensitive cities; water sensitive design

Issue
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1. Introduction

As South African cities urbanise alongside climate change, resource constraints, and socio-economic challenges, water sensitive urban design (WSUD) is slowly gaining traction as a framework to address water security goals and entrench resilience (Carden et al., 2016; Fisher-Jeffes et al., 2017). The country's urban areas are a patchwork of highly unequal formal and informal areas that are afforded varying levels of infrastructure and urban water services. Current path dependencies have locked in an approach of "grey" built water infrastructure, and the centralized water provision and planning and management models supporting it. WSUD offers an alternative systems based approach through its supporting principles of resilient, adaptive, and sustainable urban water systems (Wong, 2006; Wong et al., 2020); and a water sensitive city (WSC) intentionally plans for equity and liveability through a combination of physical infrastructure, social engagements, and institutional arrangements (Brown et al., 2016)—although this has yet to be comprehensively tested in developing countries around the world. Almost a decade ago, South Africa began engaging with the potential of WSUD to address its urban challenges (Armitage et al., 2014), initially mostly through an emphasis on stormwater-based infrastructural interventions, but this has since broadened to include institutional elements and water sensitive planning (Fourie et al., 2020a). WSUD is increasingly referred to as water sensitive design (WSD) in South Africa to allow for a broader focus on the development of not only urban and peri-urban communities, but also those in rural environments (Carden et al., 2016). Increasing urbanisation in South Africa has led to the proliferation of peri-urban areas which often take the form of informal settlements or slums. For WSD to be applicable and relevant to the South African context, the concept needs to be able to account for informality. The terms WSUD and WSD are therefore used interchangeably in this document.

In South Africa, water resource management is often considered late in the municipal planning process and in isolation from other urban services (such as transport networks, for example). It typically features a professional culture of civil engineering and other technical experts. Emphasis has largely been placed on expanding water services provision to unserviced communities to redress Apartheid-era inequalities at the expense of maintaining infrastructure and neglecting environmental capital (Cilliers & Rohr, 2019). This has had knock-on impacts for water quality, particularly as water and wastewater systems take strain from unchecked development. The legacy of Apartheid still lives on across cities, with stark inequalities between formal and highly dense informal areas, the latter remaining poorly serviced with infrastructure backlogs. WSD is seen as an enabler that could ensure both the equitable provision of water services and the creation of cities with enhanced ecosystems, liveable urban spaces, and resilient multi-functional water infrastructure.

Given the nature of the country's urban challenges, embracing and operationalizing the principles of WSD requires significant intentional effort. There are large gaps between theory and practice in municipalities and industry, and water sector stakeholders are in general not skilled to engage with the concept. Tensions exist between the need to address basic water and sanitation service provision and provide water related liveability outcomes associated with the visionary state of a WSC. There is still limited—albeit growing—experience with the implementation of multi-functional WSD measures (including Sustainable Drainage Systems [SuDS], for example), which pose new challenges for all decision makers and necessitate the involvement of multiple disciplines and supporting policies (Dominguez et al., 2009; Tjandraatmadja, 2019). A national WSD Community of Practice (CoP) has been active since the WSD Framework and Guidelines were published by the South African Water Research Commission (WRC) in 2014 (see www.wsudsa.org). The WSD CoP has been a key driver in entrenching and advancing WSD through various knowledge sharing, capacity development, and stakeholder engagement activities, with a community-based approach to action-learning as a central element of the CoP. As will be described in further detail later in this article, Wenger (1998) argues that learning is an intrinsically social process and that one of the primary sites where learning occurs is in CoPs. The WSD learning process in different parts of South Africa can be characterised as informal and situated in social interactions, which have slowly facilitated the uptake of aspects of WSD and a growing commitment to a transition to WSCs.

This article reflects on the progression of WSD in South Africa and discusses the broadening of its initial association with stormwater and physical infrastructure to include critical institutional arrangements and planning processes. The role of the WSD CoP and the associated social learning processes are described. Following this, three related cases from South African cities are presented, demonstrating the type of institutional arrangements and social learning processes related to WSD that are occuring in the country.

2. The Evolution of Water Sensitive Design in South Africa

2.1. Water Sensitive Urban Design and Water Sensitive Cities

WSUD offers an alternative systems-based approach to conventional centralised urban water management and encompasses all aspects of integrated urban water cycle management, including water supply, sewerage, and stormwater. SuDS constitute the stormwater management component of WSUD and consist of a range of technologies and techniques used to drain stormwater/surface water in a manner that is more sustainable than conventional solutions. SuDS are based on the philosophy of replicating as closely as possible the natural, pre-development drainage from a site, and are typically configured as a sequence of stormwater practices that work together to form a management train (Fletcher et al., 2014). The WSUD concept brings sensitivity to water in urban water planning and management and focuses on integrating the urban water cycle into the built and natural environment to enhance sustainability, liveability, and resilience (Wong & Brown, 2009). A WSC moves beyond the goal of the provision of water services to the creation of cities with enhanced ecosystems and increased biodiversity, liveable urban spaces with amenity and resilient multi-functional water infrastructure, among others (Brown et al., 2016)—with a view to protecting the health of receiving waterways, reducing flood risk, and creating public spaces that harvest, clean, and recycle water.

In contrast to WSUD, conventional approaches to urban water management typically rely on large, centralised storage, conveyance and treatment infrastructure, and a single water source. The paradigm is characterized by a professional culture of civil engineering and technical experts, assumptions of stability and predictability, centralised provision of services, highly localised organisation structures, and strong state regulation. There are strong path dependences that lock-in this approach, and which are supported by planning and decision-making structures that often perpetuate conventional infrastructure investments (Truffer et al., 2010; Walker, 2000).

The three pillars of a WSC, i.e., cities as water supply catchments, cities providing ecosystem services, and cities comprising water educated communities, formed the basis for the Principles for a City of the Future as presented in the document *blueprint2013—Stormwater Management in a Water Sensitive City* (Wong et al., 2013). Following a series of practitioner envisioning workshops in Australia, Binney et al. (2010) adapted the vision to highlight four themes and 12 principles (Figure 1). The vision emphasizes the importance of including communities, members of the public, and water professionals, and the need for their multiple values of water to be expressed. Networks between communities coupled with their active participation in water systems are highlighted for building WSCs. Proactive, strategic, and collaborative spatial planning is a core feature of the vision of the City of the Future. City planning, infrastructure, and service delivery are achieved through a partnership between urban planners, the water sector, and other key sectors. Historically, the water sector has limited influence over the social, economic, and environmental shape and condition of cities, with the provision of water infrastructure and services considered late in the planning process. Given the expanding societal objectives and changing values for water services, urban planning and the water sector need to collaborate more to incorporate these increasingly complex objectives into urban development decisions to create WSCs (Gleick, 2003; Hoekstra et al., 2018).

2.2. Building a Community of Practice in Water Sensitive Design in South Africa

The concepts of WSUD and WSCs emerged in Australia in the 1990s and were formalised in the 2000s through the Cooperative Research Centre for Water Sensitive Cities, Australia. Following on from initial work on sustainable stormwater management at some of the larger municipalities around the country, the South African Guidelines for SuDS were published in 2013 by Armitage et al. (2013) and were closely followed by the Framework and Guidelines for WSUD in South Africa (Armitage et al., 2014). Both of these projects were commissioned by the WRC and undertaken by a team of researchers at the University of Cape Town comprising a multidisciplinary team of civil engineers, social anthropologists, environmental scientists, urban planners, political scientists, landscape architects, urban ecologists, and hydrogeologists. The process included significant stakeholder engagement through workshops and interviews with municipal officials from the Roads and Stormwater, and Water and Sanitation Departments of

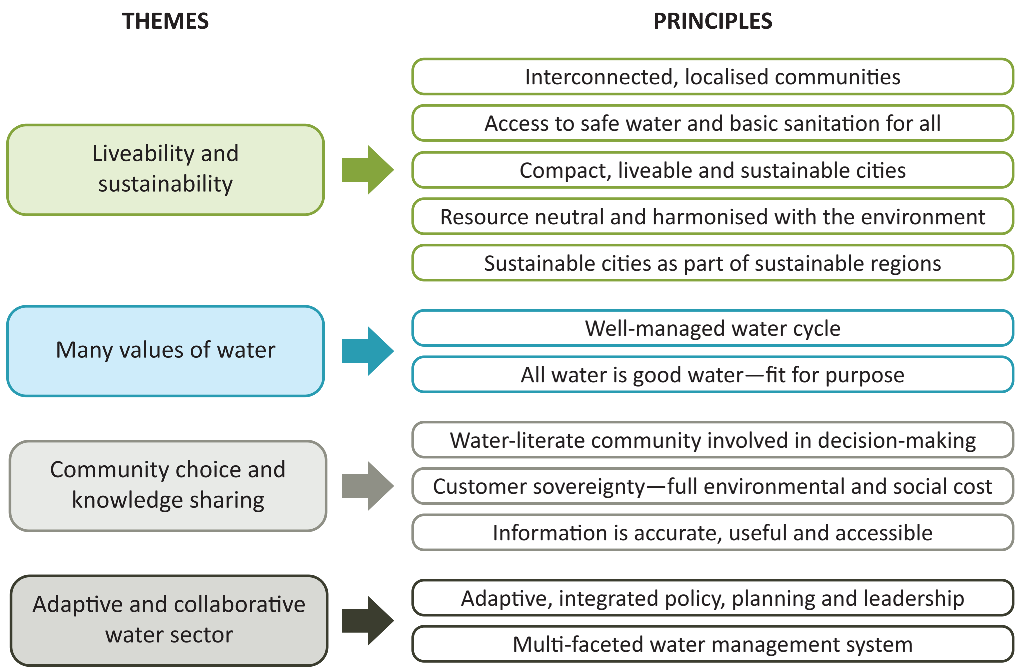

Figure 1. Principles for a City of the Future. Source: Wong et al. (2013, p. 8).

four of the major metropolitan municipalities—Cape Town, eThekwini, Johannesburg, and Tshwane, as well as Drakenstein, a smaller local authority near Cape Town (Fisher-Jeffes et al., 2017). Environmental planners and stormwater engineers were particularly influential in this process, with their inputs driving the significant focus on stormwater and infrastructure-based interventions. It was at this time that the decision was made to expand the term WSUD for the South African (i.e., developing country) context so as to include a broader focus on peri-urban and rural areas also; thus, WSD became the preferred terminology.

Early in the guidelines' development process, the concept of "learning alliances" was recognised as an important mechanism to drive WSD uptake and implementation. Butterworth et al. (2011, p. 3) define learning alliances as "platforms that bring together stakeholders from a range of institutions… to think, act and learn together, using action research to test ideas." Networks and relationships, both informal and formal, between and within the project team and stakeholders from the various workshops, provided lessons and a foundation for proposing WSD as a new approach to water management in the country. This insight then led to the establishment of Phase 1 of the WRC-supported WSD CoP programme which ran from 2014 to 2019, and played a key role in awareness-raising and knowledge integration in the field of WSD in South Africa (Carden et al., 2016). As will be described in more detail later in this article, the WSD CoP is currently in the final year of the Phase 2 programme (2019 to 2021) with a strong focus on strengthening its profile and impact narrative towards more widescale implementation of WSD.

The most widely-cited definition of a CoP is "… groups of people who share a concern or passion for something they do and learn how to do it better as they interact regularly" (Wenger, 1998, p. 1). The necessary components of a CoP include a domain (area of shared interest), a community (sense of belonging among members), and a practice (action-learning through participation and reification). A CoP can also be viewed as a community-based social learning approach to action-learning that aligns with the tradition of systems thinking (Blackmore, 2010). In other words, a CoP is not simply a group or groups of people but rather a social process of negotiating competence in a domain over time. Social learning processes offer potential to build capacity to achieve joint solutions and to make stakeholder participation effective—both critical elements for effective water governance in the context of increasing uncertainty and complexity such as that brought about by climate change and rapid urbanisation. In this regard, Pahl-Wostl et al. (2013) provide compelling arguments for a shift in emphasis from information generated from scientific research that merely informs policy and expert cycles, to strategic partnership approaches that consider multi-perspective and multi-scale knowledge in the pursuit of sustainable water futures. Thus, the social learning embedded within a CoP structure offers a useful framework with tools and methods to analyse and structure the pursuit of WSD at all levels of society, be it at neighbourhood, catchment, city, or country scale.

Given that water resources, as well as WSUD initiatives, can be seen as "common pool" resources, a CoP approach to transitioning to WSCs is of broad value (Leonard et al., 2019). CoPs have played important roles in various countries in adopting sustainable and water sensitive approaches. For example, Gonzalez et al. (2011) detail the role of engaging researchers and practitioners through a CoP in developing urban sustainability indicators for five European cities, with the CoP bridging the gap between science and practice and facilitating the selection of meaningful indicators. Allen (2012) advocates for the role of a green infrastructure CoP in the United States and the use of their website to highlight best practice planning and implementation examples across scales and jurisdictional boundaries as well as to convene conferences to facilitate engagement and social learning.

2.3. Water Sensitive Urban Management and Water Sensitive Urban Planning

The 2014 Framework and Guidelines for WSUD in South Africa split the WSD term into three components to be considered in an integrated manner, including: i) WSUD brings the concepts of "water sensitivity" and "urban design" together to ensure that "urban design" is undertaken in a water sensitive manner; ii) water sensitive urban planning (WSUP) deals with urban planning and governance aspects to ensure that this is undertaken in a manner that considers and treats water sensitively; and iii) water sensitive urban management (WSUM) deals with the post construction management of water sensitive infrastructure (Armitage et al., 2014).

The first few years after the 2014 framework was published were largely focused on WSUM, as both local government and industry-based professionals (mainly engineers and scientists) grappled with embracing and operationalizing the concept in their respective contexts. In order to implement WSD interventions at that time, emphasis was placed on ensuring technical performance of related infrastructure and establishing the benefit costs and maintenance requirements of these interventions compared to conventional "grey" infrastructure. The early stages of WSD in South Africa were also principally focused on stormwater management. WSUM continues to be a focus in South Africa, with increasing WSUD infrastructure projects. These projects range from the implementation of green infrastructure (often SuDS), which tend to be located within private developments (Shackleton et al., 2018), to hybridised "grey-green" infrastructure. Retrofitting green infrastructure options alongside existing grey infrastructure is increasingly being trialled as an approach towards WSD implementation in South Africa, where limited resources—both human and financial—most often need to be utilised for basic service provision. For example, the City of Cape Town has committed to a Liveable Urban Waterways programme through its recent Resilience Strategy (City of Cape Town, 2019a). The programme seeks to rehabilitate urban waterways (largely concrete channels) using WSD principles and through the use of retrofitted green infrastructure. The 2014 WSD framework also advocates for retrofitting infrastructure, especially stormwater infrastructure, for amenity and water quality improvement purposes (Armitage et al., 2014).

For the true expression of WSD, and for the concept to have maximum impact, planning needs to play a crucial role so that WSD principles are strategically included from the start, and at all spatial scales from the metropolitan to the site level (Fourie et al., 2020b). South African cities present complex water planning challenges as a consequence of the fierce competition for land and housing and the dynamic patchworks of formal, informal, and backyarder (i.e., "… secondary dwellings in low-income areas… considered additional structures to the main house and may range between different levels of formality and informality" [Isandla Institute, 2020, p. 4]) housing developments that require different levels of water services. Water departments and spatial planning departments typically lack integration, complicating the realisation of WSCs which depend on strategic urban design and planning (Cilliers & Rohr, 2019). Moreover, the principles of WSD and WSCs are largely foreign in spatial planning departments in South Africa, with professionals lacking the understanding and competencies needed to spatially integrate WSD into the urban form. Following on from the SuDS and WSD Guideline documents therefore, the publication of the WRC-supported Guidelines on Compiling Water-Sensitive Spatial Plans and Framework Towards Water-Sensitive Spatial Planning and Land Use Management (Fourie et al., 2020a, 2020b) have gone some way to addressing these issues, offering an important starting point for increasing the prominence of urban planning and design in realising WSCs (Figure 2). These two documents provide guidance on spatially translating WSD at the municipal (city) scale within the bounds of South Africa's complex planning legislation. The documents detail various legislative elements pertaining to water resources that exist at national, provincial, sub-catchment, municipal, and area levels that involve multiple stakeholders. However, there is still a long way to go in terms of the development of appropriate tools, stakeholder partnerships, and regulatory and policy structures within local governments to enable the level of integration of planning and water management required to effect a transition to water sensitivity. As water sensitive spatial planning is still in its infancy in South Africa, there are few examples and case studies in the country that the WSD CoP can use to facilitate learning.

3. Social Learning Associated With the Water Sensitive Design Community of Practice

The initial phase of the WSD CoP programme (2014 to 2018) included purposeful engagement with a wide group of stakeholders and promoted knowledge integration in the field of WSD through, *inter alia*, an expanded training programme with a combined reach of over 1,000 water stakeholders in both the public and private sphere in South Africa (Carden, 2019). It was able to indicate that this approach has the potential to generate new understandings about innovative practices and reflexive learning within WSD in South Africa, and to develop knowledge connected to policy development and change to influence planning and design towards WSCs. The main focus areas of the first phase of the WSD CoP programme were:

Figure 2. Milestones in the evolution of WSD in South Africa through the publication of guidelines and the establishment of the WSD CoP programme. Source: Authors, based on Armitage et al. (2013, 2014) and Fourie et al. (2020a, 2020b).

- The identification of possibilities for collaborative and participatory interaction between all relevant actors, including awareness-raising and appropriate WSD training activities—including those hosted collaboratively with partners such as the Centre for Science and Environment (CSE) in India. The training partnership with CSE was established in 2017 with the specific aim of broadening the impact of the WSD capacity-building component of the CoP; in particular, by introducing practical elements on rainwater harvesting and decentralised wastewater treatment from a developing country perspective. CSE India is a public interest research and advocacy organisation based in New Delhi, set up to act as a Centre of Excellence in the area of sustainable urban water management. The collaboration with them enables the sharing of solutions with other countries in the developing world (including other African countries) that engage in common struggles around meeting the water and wastewater treatment needs of urban and rural populations which are affordable and sustainable;
- The establishment of smaller CoPs or learning alliances in different geographic locations with the objective of linking the various actors in these urban water systems and promoting shared learning and innovation around sustainable water management practices. These platforms allowed researchers, local stakeholders, and users to work together to create shared visions, analyse options, and develop new strategies for the management of diverse forms of urban water infrastructure systems;
- Documenting case studies to consider and develop/modify social learning frameworks for adopting WSD mechanisms in the South African context—including the various ongoing and potential projects around the feasibility of WSD strategies, as well other relevant WRC projects related to WSD, e.g., WRC Project K5/2587 "Securing Water Sustainability Through Innovative Spatial Planning and Land Use Management Tools—Case Study of Two Municipalities," that produced the guidelines for developing water sensitive spatial development frameworks and water sensitive land use schemes (Fourie et al., 2020a, 2020b).

The Phase 1 CoP also highlighted some gaps and/or shortcomings however, specifically in terms of the necessity for more targeted training on WSD and planning, broader engagement with a wider group of stakeholders, and for an expansion of the CoP (and strengthening of its profile and impact narrative) in areas other than large metropolitan cities. A second phase of the programme was thus established to run from 2019 to 2021, with the overall aim of facilitating a more widespread uptake of WSD in South Africa.

Some examples of the different types of social learning that have been enabled as part of the South African WSD CoP are provided in the sections that follow, which also attempt to highlight the need for integrative approaches in the planning for WSCs. All of the case studies discussed are ongoing (current in 2021) projects that are beginning to show what is required in order to plan for and transition towards WSCs.

4. Local WSD CoPs and Case Studies

This section describes three South African examples that demonstrate the value of a CoP approach with social learning processes.

4.1. Pathways to Water Resilient South African Cities Project

Academics at the interdisciplinary Future Water Research Institute at the University of Cape Town and the University of Copenhagen, Denmark, have partnered on a research project entitled "Pathways to Water Resilient South African Cities" (PaWS). The current project aims to identify opportunities for, and generate knowledge on, the physical and institutional integration of decentralised nature-based solutions into the urban water cycle to support and accelerate a transition towards water resilience in South African cities, specifically focusing on the cities of Cape Town and Johannesburg. The project is split into physical and institutional work packages, with the former including physical experimentation and evaluation of WSD options at different urban scales, particularly focusing on repurposing urban stormwater ponds for the treatment and harvesting of surface runoff through managed aquifer recharge and recovery. The latter explores the required governance processes and institutional arrangements for enabling WSD emergent transitions.

The main novelty and contribution of the project lies in the dual consideration of the physical and institutional pathways to water resilience, which historically have been considered separately in WSD-focused South African research. WSD-directed South African research either focuses on infrastructure selection, construction, and evaluation, or the governance and institutional arrangements, and infrequently the planning practices supporting WSD. The interdisciplinary project team therefore intentionally designed the project to explore the links, feedback loops, and supportive structures between infrastructure measures and institutional and planning environments and processes. From the outset, a co-design approach was adopted in both the design of the physical experiments as well as the evaluation of institutional pathways, with a strong focus on social learning processes with identified stakeholders to allow for WSD thinking to be embedded effectively.

The project focus was driven in part by the City of Cape Town's increasing engagement and policy alignment with WSD that spans back to 2009, as well as the recent drought and associated "Day Zero" crisis that was largely as a result of significantly below average rainfall during the period 2015 to 2017 (Otto et al., 2018; Wolski et al., 2020). Cape Town relies on conventional centralised water management and planning approaches, with a water supply highly dependent (95%) on six large rainfed dams located outside of the city boundaries. The water crisis thus became a primary driver of a focused move towards water sensitivity, an acute shock that drove the need for a consolidated water sensitive vision for Cape Town. This was articulated through the document *Cape Town Water Strategy—Our Shared Water Future*, published in 2019 (City of Cape Town, 2019b). However, WSD had slowly been gaining traction even prior to this drought. As part of the PaWS project, an analysis of the evolution of WSD related planning policy in Cape Town up until 2019 was conducted to highlight the development of institutional pathways towards water resilience (see Figure 3 and the description below). Fifteen policies dating back to 2009 were analysed for the inclusion of WSD principles and for advocating the approach across various organisations and departments.

Prior to the development of the national WSUD Framework and Guidelines in 2014, the City of Cape Town's Catchment, Stormwater and River Management Branch pioneered the adoption of a WSD-centred approach to stormwater management. Two policies were published in 2009—the *Floodplain and River Corridor Management Policy* and the *Management of Urban Stormwater Impacts Policy*—both of which required developers to adopt a WSUD approach and were key in driving the uptake of sustainable drainage technologies in particular (such as permeable pavements). In 2013, the Urban Design Policy also advocated for WSUD principles, again framed from a drainage-related perspective; however, there was also acknowledgement of the multi-functional aspects of WSD. This policy was developed with a range of City departments such as Transport (including stormwater management), Water and Sanitation, City Parks, and the Planning and Building Development Management Department. The inclusion of these principles in the policy marked a milestone for WSD in Cape Town, as it heralded the beginning of inter-departmental collaboration in the formulation and uptake of WSD-related policy. In 2017, WSUD was included in three major documents: the *City of Cape Town Climate Change Policy*; *Water Services Development Plan—Integrated Development Plan Water Sector Input Report* (2017/18–2021/22) and the *Municipal Spatial Development Framework* (2017–2022). The *Water Services Development Plan—Integrated Development Plan Water Sector Input Report*

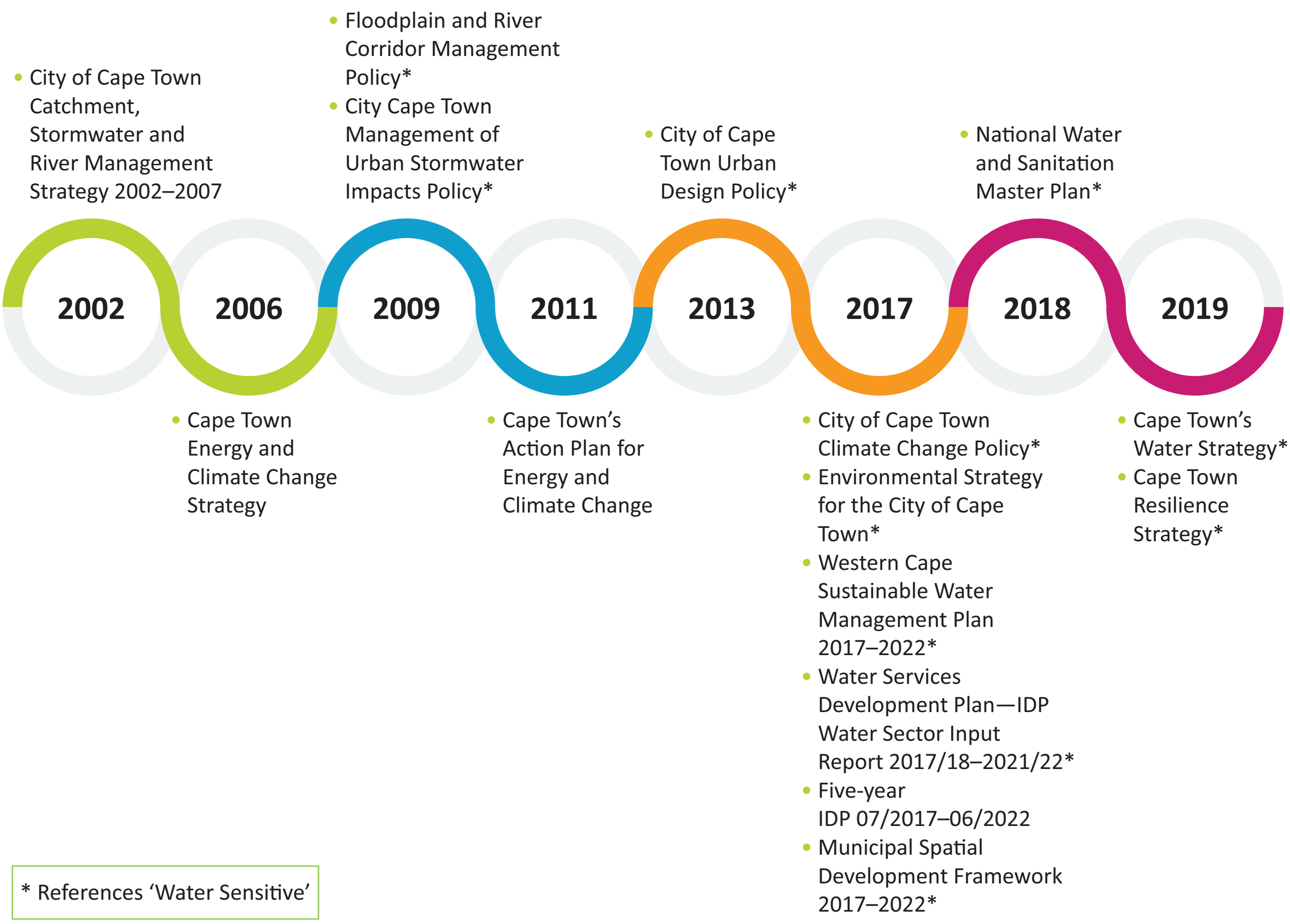

Figure 3. Timeline of selected water policy in Cape Town illustrating the emergence and evolution of WSD/WSC principles.

articulated a vision "to be a beacon in Africa through the progressive realisation of Cape Town as a water sensitive city" (City of Cape Town, 2017, p. 14). Climate change was cited as a major reason for the paradigm shift to water sensitivity, and the plan was mostly resource and infrastructure management and service delivery oriented. The City of Cape Town has continued with this policy alignment to WSD principles, releasing the Water Strategy with its commitment to becoming a WSC by 2040, as well as the Resilience Strategy (City of Cape Town, 2019a) which also addresses the linkages between water security and other potential shocks (e.g., storm surge and flooding) whilst acknowledging the underlying chronic stresses that weaken the City's ability to respond, such as informality, unemployment, and climate change.

These targeted policy interventions provide the institutional foundation for the integration of WSD into city water planning and management processes and have gone some way to supporting the physical manifestation of multi-functional infrastructure, particularly in respect of SuDS. The evolution of WSD/WSC in the policies from various departments highlights different disciplinary perspectives and illustrates the need for many professions to contribute to WSD. The institutional foundation these policies provide for WSD highlights the skillsets and knowledge required for implementing WSD.

Nonetheless, progress in the City of Cape Town's emergent transition towards water sensitivity continues to be slow—mainly as a result of a dearth of city-specific business cases to support a more coherent adoption of WSD, and a lack of coordination of roles and responsibilities (Mguni & Carden, 2020). The PaWS project has highlighted the need to build evidence for contextual resilience-building initiatives through engaging in physical and governance experimentation in cities to provide a space for the reconfiguration of capacities, resources, and agency of institutional, business, and civil actors in support of transformative change. Through mapping the various WSD options as well as the identification of participants for the multi-actor transition arena processes (i.e., structured engagements such as workshops and focus group discussions that are aimed at enabling a common understanding amongst stakeholders of the transition challenge faced by cities in the uptake and implementation of a WSD approach), the project has started to address the governance and policy implications of hybridising conventional water infrastructure with green infrastructure in a WSD approach.

4.2. Gauteng Department of Rural and Agricultural Development SuDS Training Programme

WSD has also been gaining traction in other provinces around South Africa, specifically in terms of the stormwater management component; for example, the *Gauteng Sustainable Drainage Systems (SuDS) Implementation Manual* (Gauteng Provincial Government, 2020) was recently published, which strongly promotes the principles of WSD. In an attempt to ensure the wide-scale uptake of the concepts within the Province, the Gauteng Department of Agriculture and Rural Development (the department responsible for the development of the Manual) has undertaken to support a targeted SuDS capacity development and training initiative as part of an intergovernmental skills development programme. This programme is being coordinated through the University of Johannesburg's Process, Energy and Environmental Technology Station who facilitate the collaboration with the Gauteng Department of Agriculture and Rural Development and define future work aligned with the creation of a dedicated CoP within a triple helix network (i.e., structured interactions between academia, industry, and government that are aimed at fostering economic and social development) around SuDS uptake in Gauteng. The overall intention is to create a group of stakeholders skilled in WSD and SuDS who can start to forge relationships with industry partners and research institutions in the ongoing implementation of SuDS projects.

In recognition of their expertise in the field of SuDS—together with the role they have played in leading the WSD CoP on behalf of the WRC and facilitating the WSD/SuDS training programmes associated with that programme—the Future Water Research Institute have been tasked with the skills audit and training components within the University of Johannesburg's Process, Energy and Environmental Technology Station and Gauteng Department of Agriculture and Rural Development collaboration. The following activities are defined within the context of the existing WSD CoP framework to facilitate knowledge sharing, capacity development and social learning:

- Introductory workshop on SuDS that focuses on encouraging intergovernmental collaboration and establishing the basis for future work, including an overview of the process that led to the development of the Gauteng SuDS Implementation Manual;
- Facilitated SuDS skills audit and gap analysis within Gauteng Province—key stakeholders identified and brought into a carefully-crafted engagement process (including the use of interviews, surveys, and questionnaires) to determine the skills requirements related to the broader-scale implementation of SuDS across government departments in the Gauteng Province, aligned with the Implementation Manual;
- Development of customised SuDS training material for identified priority stakeholder groups and delivery of said training sessions;
- Ongoing SuDS stakeholder mapping in Gauteng Province with the goal of supporting the establishment of a targeted group of stakeholders in multidisciplinary working environments across government departments (local, provincial, and

national), academia, industry, small, medium, and micro enterprises, non-governmental organisations, and consultants.

Initial findings from this project have revealed that whilst environmental professionals are relatively well-represented in the provincial government's structures, there are many knowledge gaps in respect of SuDS implementation. Of more concern is the fact that planning, urban design, landscape architecture (LA), and policy professionals are not yet represented in discussions on the SuDS Implementation Manual, thus highlighting the strong need for awareness-raising and skills development activities in these areas.

4.3. Institute for Landscape Architecture in South Africa/South African Institution of Civil Engineering WSD Working Group

There has been growing recognition of the varied skills across built environment disciplines in South Africa (including engineers and landscape architects) where specialists in both of these areas have a range of technical abilities to implement WSD/SuDS—but often have limited understanding of the impact of their individual contributions to the broader WSD development process. As one Cape Town-based landscape architect put it, "Landscape architects are often seen by engineers as green decorators, yet we need the engineers to give practical depth to the LA's sometimes shallow understanding of the problems and safety requirements of their designs." Similarly, engineers acknowledge the critical contribution that LAs make towards building momentum in the uptake and implementation of WSD/SuDS options.

Following a series of green infrastructure webinars held by the Institute for Landscape Architecture in South Africa in late 2020 where engineering professionals were also represented, the decision was taken to try and establish a working group together with the Future Water Research Institute, that would link the two most represented professional bodies in the WSD field; i.e., Institute for Landscape Architecture in South Africa and the South African Institution of Civil Engineering. A small group was assembled representing academia, consultants, and government officials to work towards developing an action plan for enhanced collaboration across these professions, and to build technical support, training, and communication skills development for practitioners in both fields. A specific focus of the working group is to investigate opportunities for collaboration on, and documentation of, integrated green infrastructure and public space projects—with a view to building a local (African) evidence-based repository of peer reviewed case studies to use in promoting WSD/SuDS and climate conscious design of public space to professional colleagues, authorities, and developers. Through the working group sessions, a number of key priorities have been identified to develop momentum towards achieving these outcomes. These include: the development of short, continuing professional development courses with content structured for interdisciplinary access; co-authoring journal and conference papers; visits to demonstration sites led by design, construction, and maintenance teams; and communication through popular media platforms to address the inconsistencies in understandings of WSD/SuDS and to educate practitioners and members of the public of the value of such an approach.

4.4. Discussion of Examples

The three examples provided here represent simple CoPs in their own right, with characteristics of social learning systems (Blackmore, 2010) and the necessary components of a CoP, i.e., a domain (area of shared interest), a community (sense of belonging among members), and a practice (action-learning through participation and reification). The examples illustrate the importance of uunderstanding how key professions work together and where the gaps in knowledge are to ensure the necessary integration at an institutional level to support widespread implementation of WSD. In the first example, the "Pathways to Water Resilient South African Cities" project highlighted the role of an institutional foundation, with a history of supporting policy, for the integration of WSD into city water planning and management processes. The diversity of departments and disciplines reflected in the policies illustrate the multiple key professions involved in WSD. The project also highlighted the need to build evidence bases for both WSD physical and governance intervention which provide knowledge for the reconfiguration of capacities, resources, and agency of institutional, business, and civil actors. The SuDS training programme in the second example discussed a partnership between academia and governmental bodies to facilitate knowledge sharing, capacity development, and social learning. Once again, developing means to bring key professions together and ensure a broader representation of disciplines for WSD implementation was highlighted. The WSD working group with the Institute for Landscape Architecture in South Africa and the South African Institution of Civil Engineering similarly used a CoP approach with social learning to link key WSD professionals. Enhancing collaboration across these professions, and building technical support, training, and communication skills development for practitioners in both fields were key priorities.

5. Conclusions

The development of the South African WSD Framework and Guidelines, the Water Sensitive Spatial Planning Framework and Guidelines, along with the initial associated learning alliance/s and subsequent WSD CoP that was established, reflect the importance of both physical and institutional elements in transitioning to water sensitivity in urban areas. Simply publishing guidelines on WSD to enable the implementation of physical infrastructure-based interventions is not enough; this needs to be accompanied by the establishment of communities of water professionals, the support of social learning, transferring of knowledge to influential water sector stakeholders, and ensuring enabling policy environments. Three examples have been presented in this article that highlight the role and value of CoPs in bringing key professions together to learn from one another's perspectives and ensure that the necessary WSD skills and competencies exist across the country, as well as building momentum for and supporting the necessary planning processes to effect change.

From a social learning perspective, the intended outcome of CoPs is to grow "communities of communities" or "landscapes of practice" where local-level learning experiments benefit from and contribute to an overall learning system pertaining to the required transition for embedding a new paradigm such as WSD at city scale. The key insights of such a fractal structure are that the concepts of WSD become sufficiently embedded in the institutional pathways and processes related to the planning of WSCs in South Africa and beyond.

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Conflict of Interests

The authors declare no conflict of interests.

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Article

Closing the Gap Between Urban Planning and Urban Ecology: A South African Perspective

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Abstract
Ecological considerations should be an integral part of the decision-making processes of urban planners. Specifically, ecological aspects used in urban ecology, such as green infrastructure and ecosystem services, are substantiated by literature as strategies for improving quality of life, human health, and well-being. Studies dealing with such concepts in the Global South recently gained interest; however, these lack empirical evidence on the integration thereof in mainstream South African urban planning practice. This article conducts a preliminary investigation into the knowledge of ecological aspects of a sample of South African urban planners and their willingness to implement ecological aspects in urban planning practice. The new environmental paradigm scale is employed to determine the environmental worldview (ecocentric or anthropocentric) among respondents and how this relates to their knowledge of ecological aspects. The initial research sample consisted of a total of 283 questionnaires distributed. Although findings of this article are based on a low response rate (15%) of 42 documented responses, it did not affect the validity of the data collected in this context. The initial findings indicated that the environmental worldview of the sample of planners is only one factor influencing their perspective on incorporating ecological considerations. Low to moderate knowledge and awareness regarding ecological aspects such as ecosystem services, green infrastructure, and multi-functionality are argued to be main factors preventing integration in urban planning practice. Findings emphasize the need for context-based implementation strategies and broad recommendations are made for the planning profession as a point of departure to introduce or ingrain ecological considerations.

Keywords
ecosystem services; green infrastructure planning; multi-functionality; South Africa; urban ecology; urban planners; urban planning practice

Issue
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1. Introduction

Scientific understanding and support for the potential of more ecologically-minded approaches to address multiple issues faced by urban areas are gaining momentum in multiple disciplines (Escobedo et al., 2011). There has been a mounting emphasis on the discipline of urban planning, as the discipline concerned with the spatial arrangement of social, economic, and environmental spaces and activities within urban areas (Huxley & Inch, 2020), to become more holistic. In addition, urban planning should also integrate advanced urban ecological concepts, knowledge, and aspects (e.g., Osmond & Pelleri, 2017, p. 31; Tan & Jim, 2017, p. 15) related to urban ecology, as an interdisciplinary field that aims to understand how human and ecological processes could coexist in human-dominated environments to guide societies to become more sustainable (Marzluff, 2008).

These include considering concepts like urban ecosystems, green infrastructure (GI), and ecosystem services (ES; Gómez-Baggethun & Barton, 2013, p. 235). Urban ecosystems in urban ecology reference the interactions between living organisms (biota), and between biota and the abiotic environment, such as water, soil, and air (Pickett et al., 2001), to describe novel ecosystems in which human-induced changes not only affect the abiotic environment but also species diversity and interactions (Kowarik, 2011). Planning for these urban ecosystems centres mainly on the incorporation of ecological knowledge based on "nature-based solutions," as "approaches inspired by, or copied from nature" (van den Bosch & Sang, 2017, p. 373), through the implementation of GI to gain several ES (van den Bosch & Sang, 2017, p. 373). ES refer to the benefits all living species (especially humans) derive, directly or indirectly, from the capacity (function) of urban ecosystems to provide goods and services that satisfy needs and improve human health and well-being (e.g., de Groot et al., 2010, p. 260). GI is interpreted in diverse ways and spatial scales and may include a diversity of green and blue areas (Pauleit et al., 2021, p. 108) with contemporary definitions of GI referencing the "design and management of urban ecosystems to deliver a wide range of ES" (Lindholm, 2017, p. 610). Planning for GI to deliver ES is underlined by the principle of "multi-functionality" (Pauleit et al., 2011), understood as a broader concept referencing a holistic approach to combine economic, ecological, and social objectives within an area (van Broekhoven et al., 2015, p. 1005). GI multi-functionality, as the combination of different functions within a GI element to deliver multiple environmental, economic, and social benefits (Pauleit et al., 2011), is still unfamiliar and often overlooked by urban planners (di Marino et al., 2019, p. 644; Hansen et al., 2017, p. 43). Scholarship on the application of ecological aspects in planning in the Global South is limited, but has gained traction (Cilliers et al., 2021). Within Africa, South Africa has been especially well represented (du Toit et al., 2018). South Africa continues to struggle with the social, economic, and environmental inequalities of its colonial and apartheid history, evidenced in the provision of public and private urban green spaces, which was termed "green apartheid" by Venter et al. (2020), but also presents several advancements to redress these disparities. Environmentally-minded policies and legislation guide development approaches towards more sustainable outcomes, confirming commitments at national and local level (Bobbins & Culwick, 2015). The literature provides several practical examples of ecological advancements. These include a focus on natural areas in urban open space planning through Systematic conservation planning (Compaan et al., 2017) and the use of metropolitan open space systems (Boon et al., 2016), urban biodiversity corridors (Burton et al., 2017), 500 buildings with Green Star South Africa ratings by the Green Building Council South Africa (Simpeh et al., 2021), examples of GI applications such as the green growth concept integrating energy and climate change issues (Bobbins & Culwick, 2015), the development of climate adaptation plans to develop climate resilient cities (Roberts et al., 2012), water-sensitive urban planning and design (Fisher-Jeffes et al., 2017), efforts to enhance water resilience (Sutherland et al., 2019), urban agricultural practices (Steenkamp et al., 2021), and specific examples of local-level planning actions targeting the needs of the poor in terms of urban greening (Sachikonye et al., 2016). Whilst such endeavours show potential, they are rather exceptional and localised, and significant scope exists for broader commitment and application of urban ecological approaches, as is indicative for the entire Global South (Cilliers et al., 2021). This article is specifically interested in the role of urban planning in this regard. For instance, Bobbins and Culwick (2015, p. 33) acknowledge that ecological aspects remain ambiguous and are not yet fully integrated or commonly implemented in mainstream urban planning practice in South Africa, with Schäffler and Swilling (2013, p. 247) noting a lack of empirical evidence in substantiation. Huston (2018, p. 135) posits that GI has been applied to a limited extent amongst South African urban planners given several misconceptions, partly resulting from a lack of education on GI in South African urban planning curricula. Pasquini and Enqvist (2019, p. 9) reciprocally confirm a potential dearth of ecological literacy amongst South African urban planners in this regard. In relation to literacy, skills, and a general orientation towards more ecologically-minded approaches, the concept of an environmental worldview is intriguing. An environmental worldview refers to the "lens or filter" through which an individual makes assumptions about the natural environment (Kollmuss & Agyeman, 2002, p. 239). Whereas research on the proclivity of urban planning professionals with positive ecological views to implement environmentally friendly approaches has shown positive correlations, research gaps with specific reference to environmental worldviews have been noted (Wallhagen & Magnusson, 2017, p. 498). Environmental worldviews and their influence on the ecological considerations and decisions-making of urban planners in South Africa present specific gaps.

Based on these points of departure, this article is initiated with a literature review of the urban planning discipline and its theories to establish a foundation for the inclusion of urban ecological concepts in South African urban planning practice. This is followed by a brief discussion of the concept of environmental worldviews to frame the empirical research completed in the succeeding section. Section 3 elaborates on the quantitative research methodology followed to investigate a sample of South African planning respondents regarding their understanding and inclusion of core ecological aspects in practice and their environmental worldviews. Results and a discussion follow, before main conclusions and related recommendations towards context-based implementation strategies to integrate ecological considerations in mainstream urban planning practice are delivered.

2. Reflecting on the Interface Between Urban Planning and Urban Ecology

There is considerable debate regarding planning's disciplinary and professional credentials (Davoudi & Pendlebury, 2010, p. 617). For Abbott (1988) a firm core in planning cannot be identified, as it presents a cluster of interconnected theories, methods, propositions, and solutions influenced by multiple disciplines (Behrend & Levin-Keitel, 2020, p. 311). This comes at the expense of a clearly defined and exclusive intellectual foundation (Behrend & Levin-Keitel, 2020, p. 310; Davoudi & Pendlebury, 2010, p. 614). However, this is not necessarily a weakness, as increased specialisation cannot deliver the planning generalists needed to address wicked planning problems (Olesen, 2018, p. 303). The shifting focus in planning scholarship testifies to an ever-evolving and deepening discipline that draws on multiple influences to prepare planners for the complexities of the modern world. In evidence, various strands of planning theory have emerged to discuss the nature of planning and its motivations to provide meta-theoretical and philosophical foundations (Olesen, 2018, p. 304). These theories continue to inform planning curricula internationally.

Whilst it is not the prerogative of this article to discuss planning theory comprehensively, it is important to note two distinct general categorisations: theories *in* planning and theories *of* planning. The literature generally refers to planning theory as the normative meta-theories *of* planning (Olesen, 2018, p. 305) that address why planning exists and what it does or should do (Olesen, 2018, p. 305). These theories were mainly penned in the Global North, from where they have been applied fairly unilaterally (Lategan & Cilliers, 2017). Allmendinger (2009) identifies eight main clusters that represent the non-linear, divergent evolution of planning theory, including (1) systems and rational theories, (2) Marxism and critical theory, (3) new right theory, (4) pragmatism theory, (5) advocacy theory, (6) postmodernism theory, (7) radical planning, and (8) collaborative theory, coupled with collective and communicative planning. Selected behavioural theories have also been linked to planning theory development, for example related to the rational theory and its critique (Kwon & Silva, 2020, pp. 162–171).

The emergence of communicative and collaborative theory in the 1990s coincided with a renewed turn to environmental concerns and underlying scientific approaches in response to increasing environmental awareness and new environmental regulations. This sparked a re-orientation to environmental planning as a new rationale for the profession (Behrend & Levin-Keitel, 2020, p. 306) influenced by the work of park and greenbelt planners, open space preservationists, and conservationists of the past (Campbell, 1996, p. 297). By the end of the decade, following the Brundtland Report, planning's focus shifted from environmental management to an explicit normative goal to achieve sustainable development (Davoudi & Pendlebury, 2010, p. 630). Movements such as new urbanism and smart growth were further influenced by more sustainability-minded orientations (Lategan & Cilliers, 2013). Such approaches were supported and practically implemented by theories *in* planning. Theories *in* planning prescribe methodologies for the actions of planning as substantive theories within sub-fields like land use, urban design, transportation, or environmental planning (Olesen, 2018, p. 305).

Planning's fluid intellectual foundation based on influences form such sub-fields and multiple disciplines in the arts, social, natural, and engineering sciences has resulted in significant progress in theory-making and planning practice (Mazza & Bianconi, 2014, pp. 81–87, 171–184). The addition of new subjects in planning curricula has been celebrated in the name of interdisciplinarity. Yet, results have mostly produced limited multidisciplinarity that meets demands and expectations superficially in the accommodation of conflicting epistemic backgrounds to the detriment of transdisciplinarity (Davoudi & Pendlebury, 2010, p. 639). Thus, there is a need for more targeted theorising and curriculum development that integrates applicable substantive knowledge from other disciplines more specifically for planners, both theoretically and practically, to promote critical and reflective thinking as the basis for action (Davoudi & Pendlebury, 2010, p. 634).

Accordingly, critical new paradigms, sub-fields, and disciplines must be considered. An example related to planning's established interest in the environment is represented in urban ecology (McPhearson et al., 2016; Pickett et al., 2016). Different perspectives of the discipline have evolved, delineating (1) ecology *in* cities, 2) ecology *of* cities, and, more recently, (3) ecology *for* cities (McDonnell & MacGregor-Fors, 2016, p. 936; Osmond & Pelleri, 2017, p. 32). The last is emphasised in recognition that basic ecological knowledge does not provide practitioners with the necessary information and skills (Niemelä, 1999, p. 127) and that an applied outlook on urban ecological knowledge is required (McDonnell & MacGregor-Fors, 2016, p. 936). This supports the foundation of transdisciplinarity in planning (McPhearson et al., 2016, p. 202) through the co-production and synthesis of knowledge (Ahern et al., 2014, p. 255) amongst planners, engineers, designers, urban ecologists, and civic society (Childers et al., 2015, p. 3779). The ecology *for* cities approach advances a holistic view and follows a participatory process to integrate research and practice between these stakeholders as agents in urban ecosystems (McPhearson et al., 2016, p. 202), thereby, linking with communicative planning theory and again reflecting the emergence of such approaches with environmentalism in planning in the past (Behrend & Levin-Keitel, 2020, p. 306). The main aim of the ecology *for* cities approach is to build on previous interpretations and transform ecological research and knowledge into action-based practices (Childers et al., 2015, p. 3785) to enhance links between (substantive) theory and practice. Thus, strengthening the bonds between urban ecology and urban planning (Tan, 2017, p. 24) through applications such as nature-based solutions, like GI (Pauleit et al., 2017, p. 47). GI presents direct opportunities to incorporate theoretical ecological knowledge within urban planning activities (Mell, 2013, p. 29). The potential to achieve manifold objectives specifically related to the multi-functionality principle of GI has been particularly emphasised in this regard (Andersson et al., 2014, p. 448; Hansen et al., 2019, p. 99).

Several studies have commented on the ignorance of planners, or their misconceptions regarding urban ecological concepts such as GI in terms of terminology, examples, benefits, and implementation strategies (La Rosa, 2019, p. 1) that prevent broader incorporation into mainstream planning practice (di Marino et al., 2019, p. 644). Mention has been made of the general predominance of research on GI and ES from and focusing on the Global North (du Toit et al., 2021) and a lack of holistic and cross-sectoral cooperation to integrate disciplinary knowledge leading to a dearth of contextual evidence in the Global South for theorists and practitioners (Culwick et al., 2019). The need for broader research on the interface between urban ecology and planning and the translation of ecological knowledge into context appropriate planning implementation strategies has been highlighted (McDonnell et al., 2009, p. 10; Steiner, 2016). Such endeavours should investigate the knowledge and views of planning practitioners to identify barriers and challenges that prevent the incorporation of ecological approaches in planning (La Rosa, 2019, p. 1) towards measures to advance ecological literacy (Pasquini & Enqvist, 2019, p. 9) through improved education to establish a sufficient "knowledge foundation" (du Toit et al., 2018, p. 256).

2.1. Considering Environmental Worldviews Towards the Inclusion of Ecological Aspects in Urban Planning

The spectrum of an individual's environmental worldview is anchored by either an anthropocentric worldview, in which humans consider themselves independent from other organisms in the natural environment (Ntanos et al., 2019, p. 239), or an ecocentric environmental worldview indicating that humans recognise that they have an ethical responsibility towards environmental protection through co-development (Colby & Mundial, 1989, p. 8). The "new ecological paradigm scale" (NEP-scale), developed by Dunlap et al. (2000), provides a widely employed method to measure the degree of an individual's environmental worldview (Ntanos et al., 2019, p. 239). Wilhelm-Rechmann et al. (2014, p. 206) utilised the NEP-scale to investigate the relation between the environmental worldviews of South African municipal officials (including planners) and the implementation of conservation projects, establishing a positive correlation between these variables (Wilhelm-Rechmann et al., 2014, p. 206). Research on whether environmental worldviews influence the inclusion of ecological aspects such as GI, multi-functionality, and ES, more specifically in South African urban planning practice, has not yet been undertaken. The following section discusses the research methodology followed to address the issues raised in this literature review.

3. Methodology

3.1. Data Acquisition

Data acquisition took place in two phases. Firstly, a purposive sampling technique was employed to identify a sample of planning practitioners registered with the South African Council for Planners (SACPLAN). It must be noted that the planning profession in South African is still emerging and given its relative size has been classified as a "scarce skill" (Andres et al., 2018). For the first phase, 201 questionnaires were distributed via email based on a database of contact details. For the second phase, a snowball sampling technique was employed. The objective of snowball sampling is to generate a sample from a small population (Lavrakas, 2008), as presented by the small size and limited data sources available on planners in South Africa (Todes, 2009, p. 246). Participants from phase one were utilised to recruit more participants through a request to provide the email address of a fellow urban planner. The questionnaire was then distributed to the email addresses provided by the respondents from the first phase. These respondents were also requested to provide the email address of a fellow urban planner. This process was repeated until no new email addresses were gathered. As a result, an additional 82 new email addresses were obtained and 82 questionnaires distributed. A total of 283 questionnaires constituted the initial research sample with a 15% response rate (42 completed questionnaires). As highlighted by Templeton et al. (1997) a low response rate does not necessarily affect the validity of the data collected, and could still be valuable to test for non-response effects.

The questionnaire comprised of 14 main questions (both Likert-scale and open-ended questions) and one question with 15 sub-sections. Questions were categorised into three main sections: Section 1 related to the professional background of the respondent; Section 2 determined the general understanding among respondents regarding ecological aspects (GI planning, multi-functionality, and ES) and the state of inclusion of these in South African urban planning practice; and the final section focussed on the respondents' environmental worldviews and consisted of the 15 NEP-Scale-questions revised from Dunlap et al. (2000, p. 433) and Wilhelm-Rechmann et al. (2014, p. 208; included in Table 2).

3.2. Data Analysis

Data from Sections 1 and 2 were analysed to determine frequencies within responses. Data from Section 3 were analysed based on the methodology employed by Dunlap et al. (2000) and Wilhelm-Rechmann et al. (2014). Eight of the 15 items (unevenly numbered) were meant to reflect an ecocentric worldview. The seven other questions (evenly numbered) represented an anthropocentric worldview (Anderson, 2012, p. 260; Dunlap et al., 2000, p. 432). Each of the 15-items were measured on a scale from 1 to 5. The unevenly numbered questions were scored with 5 = Agree; 4 = Mildly Agree; 3 = Neutral; 2 = Mildly Disagree; and 1 = Disagree. According to Dunlap et al.'s (2000) methodology, for an ecocentric worldview the mean score for the unevenly numbered questions should present relatively high scores out of five or relatively high responses in "Agree" or "Mildly Agree" categories. The scores of the evenly numbered questions were inverted and scored as 1 = Agree; 2 = Mildly Agree; 3 = Neutral; 4 = Mildly Disagree; and 5 = Disagree, with a low score out of five or high responses in "Mildly Agree" or "Disagree" reflecting an ecocentric worldview. The overall environmental worldview of the sample was determined out of a score of 75 (the 15 items equalling the five-point scale).

For further analysis and to reach an improved understanding of respondents, the findings of selected questions were cross-tabulated and practically significant relationships determined between variables employing Cramer's V-test. A Cramer's V-test of V ~ 0.5 represents a large effect or practical significance, while a V-test of V ~ 0.3 indicates a medium effect or practical visible significance and a V-test of V ~ 0.1 only represent a small effect or practical non-significance (Ellis & Steyn, 2003, p. 52). The following section presents the results delivered.

4. Results

The data gathered were analysed as discussed (Section 2.2), interpretations were made, and conclusions were drawn as presented in the succeeding discussion. Table 1 captures the results obtained from the responses gathered.

In response to the third (environmental worldview data) and Question 14 ("please indicate your level of

Table 1. Results of the online questionnaire.

	Questions	Results
Section 1. Demographical background data	Sector of employment: • Public sector • Private sector	• 79% employed in the private sector • 21% employed in the public sector
	Professional registration (SACPLAN registration): • Technical planner • Candidate planner • Professional planner	• 86% registered as professional planners • 14% registered as candidate planners • Zero technical planners
	The year an undergraduate degree was received: • Before 1990 • Between 1991 and 2000 • Between 2001 and 2011 • After 2011	• 41% after 2011 • 12% between 2001 and 2011 • 21% between 1991 and 2000 • 26% before 1990
	Years of practical planning experience: • More than 20 years • 16 to 20 years • 11 to 15 years • 5 to 10 years • 4 years or less	• 29% less than 4 years' experience • 19% between 5 to 10 years' experience • 5% between 11 to 15 years' experience • 9% between 16 to 20 years' experience • 38% more than 20 years' experience
Section 2. Ecological perceptiveness data	Familiarisation with the ES concept: Likert-scale between 1 and 5: 1 = "Very familiar" and 5 = "Never heard of it before''	• 10% between 1 and 2 ("very familiar") • 66% ranked 3 and 4 (in between "very familiar" and "never heard before") • 24% ranked 5 ("never heard" of the ES concept before)
	Defining ES: Ranked respondents' definition based on the similarity to formulated definition: "The benefits all living species (especially humans) derive, directly or indirectly, from the capacity (function) of ecosystems to provide goods and services that satisfy needs and human well-being.''	• 32% high level of similarity • 36% moderate level of similarity • 32% a low level of similarity

Table 1. (Cont.) Results of the online questionnaire.

	Questions	Results
Section 2. Ecological perceptiveness data	Provided examples of ES: Open-ended question	• Examples of all four ES categories were provided • 9 examples related to the provisioning services category • 19 examples related to the regulating services category • 5 examples related to the cultural services category • 3 examples related to the habitat and supporting services category
	The importance of planning for ES: Likert-scale between 1 and 5: 1 = "Important" and 5 = "Unimportant''	• 88% ranked it either as "very important" or close to "very important" • 7% ranked "neutral" • 5% ranked it as "unimportant" or close to "unimportant"
	Consideration of ES in planning activities: Likert-scale between 1 and 5: 1 = "Always" and 5 = "Never''	• 43% indicated "always" or near "always" consider ES in their planning activities • 31% indicated "sometimes" • 26% indicated "never"
	Consideration GI and urban ecology in planning activities: • Yes • No	• 71% of the respondents indicated "yes," they have considered GI • 67% of the respondents indicated "yes," they have considered urban ecology
	Reasons for the consideration of the concepts:	• 39%: "own knowledge" • 36%: "the recommendation of a specialist" • 16%: "the result of public participation" • 9%: "client or tender stipulation"
	Challenges encountered in applying these concepts in practice:	• 67%: "financial limitations" • 62%: "lack of implementation strategies" • 43%: "lack of knowledge regarding the concepts" • 26%: "lack of case studies regarding the benefits thereof''
	The best definition for the concept of "multi-functionality" of spaces: • "Multi-functionality as urban land-use concept": To concentrate and combine several land-uses (e.g., residential, commercial, and institutional) to have more than one activity or socio-economic function within the same urban space • "Multi-functionality in an urban landscape": To concentrate and combine several land-uses (e.g., residential, commercial, and institutional) within the same urban space • "Multi-functionality as the GI planning principle": The GI planning principle that entails the capacity of a space to provide multiple ES within the same space.	• 71% indicated "multi-functionality as urban land-use concept" • 10% indicated "multi-functionality in an urban landscape" • 19% indicated "multi-functionality as the GI planning principle"

agreement with the following 15 items"), the NEP-scale and related 15 items were utilised to determine the environmental worldview of respondents. Table 2 presents the 15 items, as well as related responses. The results of each of the 15 items are expressed as percentages and as a mean average out of 5.

In relation to Table 2, the average mean scores for the 15 items ranged between 2.9 and 4.5 out of 5. The "ecocentric view" items (unevenly numbered questions) averaged scores between 3.8 and 4.5 out of 5, thus reflecting an ecocentric worldview. The "anthropocentric view" items (evenly numbered questions) indicated relatively low scores out of 5 (ranging between 2.4 to 3.5) that also reflected an ecocentric worldview. These results were utilised to calculate the general environmental worldview amongst respondents (a score out

Table 2. Responses of the sample of South African urban planners to the NEP-scale items.

		Cumulative Percentage					
	Nep-Scale Items	Agree	Mildly Agree	Neutral	Mildly Disagree	Disagree	**Mean**
1.	We are approaching the limit of the number of people the earth can support.	42.9	23.8	14.3	9.5	9.5	**3.8**
2.	Humans have the right to modify the natural environment to suit their needs.	9.5	14.3	28.6	14.3	33.3	**3.5**
3.	When humans interfere with nature, it often produces disastrous consequences.	47.6	33.3	9.5	4.8	4.8	**4.1**
4.	Human ingenuity will ensure that we do NOT make the earth unliveable.	7.1	35.7	31.0	14.3	11.9	**2.9**
5.	Humans are severely abusing the environment.	54.8	31.0	4.8	7.1	2.4	**4.3**
6.	The earth has plenty of natural resources if we just learn how to develop them.	35.7	33.3	7.1	7.1	16.7	**2.4**
7.	Plants and animals have as much right as humans to exist.	54.8	28.6	9.5	4.8	2.4	**4.3**
8.	The balance of nature is strong enough to cope with the impacts of modern industrial nations.	4.8	7.1	16.7	26.2	45.2	**4.0**
9.	Despite our special abilities, humans are still subject to the laws of nature.	54.8	42.9	2.4	0.0	0.0	**4.5**
10.	The so-called ecological crisis facing humankind has been greatly exaggerated.	42.9	23.8	14.3	9.5	9.5	**3.8**
11.	The earth is like a spaceship with very limited room and resources.	28.6	33.3	31.0	4.8	2.4	**3.8**
12.	Humans were meant to rule over the rest of nature.	19.0	23.8	26.2	9.5	19.0	**2.8**
13.	The balance of nature is very delicate and easily upset.	42.9	38.1	11.9	4.8	2.4	**4.1**
14.	Humans will eventually learn enough about how nature works to be able to control it.	7.1	14.3	33.3	23.8	21.4	**3.4**
15.	If things continue their present course, we will soon experience a major ecological catastrophe.	42.9	23.8	14.3	9.5	9.5	**3.8**

of 75). The lowest score was 39 out of 75, while the highest score was 73 out of 75. An average score of 56.1 out of 75 was determined. From these results the conclusion is drawn that respondents presented ecocentric worldviews. This result, according to Colby and Mundial (1989) indicates that subjects recognise that they have an ethical responsibility to the environment through co-development between nature and human activities.

To further analyse findings, selected questions were cross-tabulated and practically significant relationships determined between variables, expressed in terms of Cramer's V-test (V). Table 3 illustrates the questions selected for cross-tabulation and the results obtained.

5. Discussion

Due to the response rate reported this paper does not attempt to make broad generalisation, nor does it claim to be representative of all planners in South Africa. This research should be regarded as a preliminary investigation into and novel discussion of the links between urban planning and urban ecology, the views and application of core ecological concepts by a selection of planners and importantly, their environmental worldviews. Although the sample is small, the diversity of respondents, as evidenced by the demographic data (Table 1) suggests limited concern for bias. Results provide important initial findings that need to be tested in the future after the issue of non-responsiveness has been addressed by increasing the response rate, possibly through more personal contact with prospective respondents as suggested by Toepoel and Schonlau (2017). It is important to note that the non-responsiveness encountered amongst planners may be caused by several factors, including ignorance and lack of knowledge about the issues investigated in the survey. The majority of

Table 3. Cross-tabulations between selected questions of the online-questionnaire to the sample of South African urban planners (V refers to the results of the Cramer's V-test).

Questions Cross-Tabulated	Objective	Results
Q1 with Q10	If planners in public and private sectors consider ecological concepts in urban planning practice differently.	a) The GI planning concept: • V~ 0.073: A small effect or practical non-significance • A low correlation was found between frequency of considering the GI planning concept between planners in the public and private sector b) The urban ecology concept: • V~ 0.246: Medium effect or practical visible significance • The public sector considers the urban ecology concept more often than the private sector
Q1 with Q12	If planners in public and private sectors indicated different challenges encountered in the application of ecological considerations in planning practice.	• V~ 0.132: A small effect or practical non-significance • The most significant challenge identified by the sample of private sector planners was "financial limitations" • The most significant challenge identified by the sample of public sector planners was "lack of political will''
Q2 with Q8	If different professionally registered planners ranked the importance of planning for ES differently.	• V~ 0.127: A small effect or practical non-significance • There was no real difference between the opinion of a candidate planner or professional planner regarding the importance of planning for ES
Q3 with Q5	If the year planners received their undergraduate degree had an influence on their familiarity with the ES concept.	• V~ 0.285: Medium effect or practical visible significance • No clear correlation was indicated
Q4 with Q9	If planners' years of experience related to their consideration of ES in their planning activities.	• V~ 0.271: A medium effect or practical visible significance • Results indicated that no matter the planners' years of experience, most considered planning for ES as important • The planners with four years or less of experience were the majority group to consider planning for ES as "unimportant"
Q8 with Q9	A correlation between respondents' indication regarding the importance of ES and how often they consider ES in their planning activities existed.	• V~ 0.426: A large effect or practical significance • It was evident when planners considered ES as important (Question 8), they also indicated that they considered it in their planning activities (Question 9)
Q10 with Q13	If planners who answered "yes" in Question 10 also indicated the "multi-functionality as the GI planning principle" as the agreeable definition for multi-functionality.	• V~ 0.325: A medium effect or practical visible significance • It was evident that the 27% of respondents that answered "yes" in Question 10 also indicated "multi-functionality as a GI planning principle''
Q8 with Q14	To draw conclusions regarding the sample's environmental worldview and a correlation to how important planning for ES was ranked.	• V~ 0.325: A medium effect or practical visible significance • Respondents with a high score out of 75 (ecocentric worldview) also considered it important to plan for ES
Q10 with Q14	To draw conclusions regarding the sample's environmental worldview and connection with the consideration of ecological concepts in planning practice.	• V~ 0.176: A medium effect or practical visible significance • The sample of planners with an ecocentric worldview also considered ecological considerations in their planning activities

respondents presented low to moderate knowledge and comprehension of ecological aspects, but the majority were also adamant that it is important to plan for ES. Findings on the integration of ES as an ecological aspect in South African planning activities indicated that the ES concept is only sometimes specifically included by respondents. This result may be due to the low to moderate knowledge and literacy of the ecological concepts reported (e.g., Bobbins & Culwick, 2015; Pasquini & Enqvist, 2019). A significant finding relates to the statistical correlation between how important respondents ranked planning for ES and how often they considered ES in their planning activities. It was evident that when planners considered ES as important, they also indicated that they considered it in their planning activities. This was also reflected in the international literature, presenting that the preservation and enhancement of green spaces and their associated ES partially depend on the importance they are assigned in urban planning practice (Langemeyer, 2015, p. 45). In terms of the multi-functionality concept, findings comparable to the results obtained by di Marino et al. (2019, p. 644) and Hansen et al. (2017, p. 43) in Europe were established in that the majority of respondents were more familiar with the "multi-functionality as urban land-use concept," while "multi-functionality as a GI planning principle" was largely overlooked. To further investigate this finding, Question 13 was cross tabulated with Question 10 (Have you previously taken GI planning into consideration in your planning activities?). The results emphasised that respondents needed to be familiarised with the GI planning concept and the incorporation thereof in order to recognise "multi-functionality as the GI planning principle'' as an agreeable definition for multi-functionality.

A total of 36% of respondents indicated that the recommendation of a specialist, such as an urban ecologist, led them to consider an ecological approach in urban planning activities in the past, emphasising the transdisciplinary interaction required. Thirty nine percent of respondents indicated that their own knowledge regarding the aspects and concepts in question provided the motive for consideration in planning practice. This once again, stresses that perceived knowledge of ecological aspects and concepts influence the attitude of respondents towards the consideration of these concepts in their work. The results of the statistical analyses indicated that neither the sector of employment (private or public sector), nor professional registration, nor years of experience presented any correlation with the integration of ecological considerations in planning practice. Challenges identified by respondents included financial limitations and a lack of implementation strategies. Both Cilliers (2019, p. 455) and du Toit et al. (2018, p. 250) specifically mention budgetary constraints as a challenge to GI planning in the South African context. While du Toit et al. (2018, p. 250) also considered lack of expertise, or strategies, for the implementation and management of ecological aspects such as GI in African cities. It is permissible to suggest that findings raise further questions surrounding the influence of a planner's environmental worldview and the importance ascribed to planning for GI and ES. Research findings indicate that respondents included in this survey did not fail to include ecological aspects such as ES, GI planning, and multi-functionality in mainstream urban planning practice because they present "wrong environmental worldviews," in fact the majority exhibited ecocentric worldviews, but that they present inadequate knowledge of key ecological aspects and implementation strategies to incorporate these considerations into urban planning practice.

6. Conclusions and Recommendations

This study provides a point of departure to call upon a better integration of ecological aspects in urban planning practice, especially pertaining to the South African context. The literature review presents important considerations on the links between planning as a discipline and its theoretical foundation in relation to urban ecology, linkages as part of planning's interdisciplinary underpinning, and potential in terms of the ecology *for* cities approach. The empirical investigation presents a pilot study to further enhance an integrated approach. The scope and sample sizes utilised in future research endeavours may be expanded to substantiate the initial findings presented and address non-response bias. The conclusions drawn from this research provides valuable insight to direct future planning education, research, and practice to shape the planning profession.

This article supports the argument that there is a need to construct context-based implementation strategies to better integrate ecological considerations within mainstream urban planning. To steer such an integrated approach and to introduce or ingrain ecological considerations as part of broader planning approaches the following recommendations are proposed:

1. A *transdisciplinary planning approach* should be prioritised as part of planning decision-making. Transdisciplinary planning approaches can, in this sense, also strengthen resilience in and through planning;
2. The principle of *multi-functionality* should be further investigated and developed for context-based implementation to establish an interface between urban planning and ecological considerations;
3. In an attempt to prioritise ecological objectives as part of mainstream planning approaches, both the *non-monetary and monetary values* linked to ecological considerations should be captured and considered within a local context;
4. Ecological considerations should be better articulated in *spatial planning policy and legislative frameworks* that direct land-use, zoning, and development guidelines, especially within the

Global South where such aspects are applied to a more limited extent than in the Global North;

5. The *educational agenda* should be strengthened and planning pedagogy revised to enable current practitioners and future planners to interpret ecological considerations as part of broader planning approaches.

These recommendations will contribute towards the development of the "ecological wisdom" (Steiner, 2018, p. 124) that urban planners need to be relevant across different scales, communities, and regions. Increasing the ecological knowledge of urban planners will enhance their ability to contribute and develop their skills in stakeholder platforms such as city labs and research action partnerships (e.g., Cockburn et al., 2016), and, in that way, enable them to contribute constructively towards research and the planning, implementation, and governance of urban GI (Pauleit et al., 2021, p. 132). The recommendations presented in pursuit of ecological wisdom are considered a point of departure to gain momentum and close the gap between urban planning and urban ecology, supported by the South African perspective captured in this article.

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Conflict of Interests

The authors declare no conflict of interests.

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