Urban Planning
Open Access Journal | ISSN: 2183-7635

Volume 6, Issue 1 (2021)

Urban Planning and Green Infrastructure

Editors

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COGITATIO

Urban Planning, 2021, Volume 6, Issue 1
Urban Planning and Green Infrastructure

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

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Available online at: www.cogitatiopress.com/urbanplanning

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2021, Volume 6, Issue 1, Pages 1–4
DOI: 10.17645/up.v6i1.3957

Editorial

City Planning and Green Infrastructure: Embedding Ecology into Urban Decision-Making

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Submitted: 22 December 2020 | Published: 26 January 2021

Abstract
Green infrastructure (GI) includes an array of products, technologies, and practices that use natural systems—or designed systems that mimic natural processes—to enhance environmental sustainability and human quality of life. GI is the ultimate source of the ecosystem services which the biotic environment provides to humanity. The maintenance and enhancement of GI to optimise the supply of ecosystem services thus requires conscious planning. The objective of this thematic issue is to publish a cross-section of quality research which addresses how urban planning can contribute to the conservation, management, enhancement, and creation of GI in the city. The terms of reference include the technical, economic, social, and political dimensions of the planning/GI nexus. Here we offer a brief overview of the articles published in this collection, and consider where policy, planning, and design relating to urban GI may be heading in the future.

Keywords
biophilia; ecosystem services; green infrastructure; habitability; sustainability; urban design; urban ecology

Issue
This editorial is part of the issue "Urban Planning and Green Infrastructure" edited by Paul Osmond (University of New South Wales, Australia) and Sara Wilkinson (University of Technology Sydney, Australia).

1. Introduction

Urban green infrastructure (GI) has been described variously as comprising a cross-city network of greenery, or a more loosely defined assemblage of diverse green elements such as parks, domestic gardens, street trees, and green roofs and walls. Here we apply a broad definition, adopted from a recent project to develop an evidence base for embedding ecology into urban decision-making: GI is "an adaptable term used to describe an array of products, technologies and practices that use natural systems—or designed systems that mimic natural processes—to enhance environmental sustainability and human habitability (quality of life)" (Davies et al., 2017, p. 31). The operative words here are 'to enhance sustainability and habitability.' If we acknowledge the city as human habitat (Moudon, 1997), then sustainability and habitability represent core objectives for urban planning, from city-wide scale to the neighbourhood and to individual buildings.

To pose the question from a different angle, GI is the ultimate source of the ecosystem services which the biotic environment provides to humanity. These include supporting services, necessary for the production of all other ecosystem services; provisioning services, products obtained from ecosystems; regulating services, benefits derived from the regulation of ecosystem processes; and cultural services, the nonmaterial benefits people obtain from ecosystems (Millennium Ecosystem Assessment, 2005). *Urban* GI is a subset of the above, incorporating both the restrictions inherent in being circumscribed by built form, and the particular benefits necessary to enhance urban quality of life and ecosystem health. The maintenance and enhancement of GI to optimise the supply of ecosystem services for the city thus requires conscious planning, from room to region (Beatley, 2011).

The objective of this thematic issue is to publish a cross-section of quality research which addresses how urban planning can contribute to the conservation, management, enhancement, and creation of GI in the city. The terms of reference include, but are not limited to, the technical, economic, social, and political dimensions of the planning/GI nexus.

2. Overview of This Issue

Building up or spreading out (Mahtta, Mahendra, & Seto, 2019), and combinations thereof, represent the options to accommodate urban growth—which itself is a given, as the rural-urban population balance shifts increasingly towards the city dweller. The first two articles in this issue examine strategies for integrating urban green space with the densifying city, although from different perspectives. Erlwein and Pauleit (2021) note the supply of urban green space is often at cross purposes with increasing demand for housing. Their article investigates the interaction between densification and the availability of green space from the perspective of summer heat stress, via a set of eight hypothetical densification scenarios. Application of the microscale urban climate software ENVI-Met to model these scenarios in Munich, Germany, demonstrates that preserving existing trees has the greatest impact on outdoor thermal comfort. The authors conclude that protection of mature trees during urban redevelopment projects will become more urgent in a climate constrained world, alongside mobility strategies for slowing the proliferation of car parks, a major cause of tree removal. The second density-focused article, from Bush, Ashley, Foster, and Hall (2021), similarly underlines the challenge of retaining and maximising urban greenery in densifying cities. The authors, from Melbourne, Australia, note an increasing focus on policy mechanisms for integrating GI into the private realm. They report on a participatory and transdisciplinary research project which informed the creation of a ‘Green Factor’ tool for application to building development proposals in their city.

As well as policy mechanisms and cross-disciplinary technical capacity, availability of adequate *resources* is critical to the establishment and long-term maintenance of urban GI. Cavada, Bouch, Rogers, Grace, and Robertson (2021) point out the difficulties involved in securing such resources, arguing that generally people and organisations take steps to allocate resources when they can see value accruing to them. Their article describes a case study relating to a woodland in Birmingham, UK, where stakeholders came together to identify value-generating opportunities for their own organisations within the framework of a social-enterprise business model. The authors report that while stakeholders can identify opportunities, limitations due to communication, time, and methodology can constrain the business model, highlighting the importance of social-enterprise entrepreneurs as catalysts and long-term enablers.

The fourth article in this thematic issue, by Matsler, Miller, and Groffman (2021), likewise emphasises the social, ecological, financial, and political challenges involved in urban GI implementation. The authors discuss comparative case studies of GI development in Portland and Baltimore, USA, through the lens of an integrative ‘Social, Ecological and Technological Systems’ (SETS) analysis. They point out that this approach can complement standard planning processes by shedding light on potential trade-offs. The SETS ‘eco-techno’ spectrum thus “becomes a platform to explore the institutional knowledge system dynamics of GI development” (Matsler et al., 2021, p. 49), identifying gaps and promoting solutions.

Building capacity around policy, planning, design, and management of GI demands *human* as well as institutional and capital resources. Noting that professional bodies have highlighted the need for spatial planners to understand and implement urban GI, Frank, Flynn, Hacking, and Silver (2021, p. 63) ask what kind of specialised knowledge planners may need “and moreover by whom and how GI knowledge and competencies may be conveyed?” They found that the status quo relies heavily on continuing professional education and ad hoc opportunities in higher education, leading to a fragmented knowledge base and limited theoretical foundations. Frank et al. (2021, p. 63) conclude that a “systematic inclusion of green infrastructure knowledges” in existing planning curricula is necessary to facilitate effective urban GI implementation.

‘Doing less bad’ is clearly necessary, but certainly not sufficient for the transition to sustainable urbanism. The final article in this collection, by Thompson and Newman (2021), focuses on the concept of *regenerative* cities. Such cities, they explain, rely on eco-efficiencies, the circular economy, and net positive energy and water management to deal with issues such as climate change. Thompson and Newman (2021) also reference an *ecological* approach to urban planning and design. Their article acknowledges the tensions between regenerative (‘pro-density’) and ecological (‘anti-density’) approaches and focuses on how combining GI with biophilic urbanism can help to reconcile these paradigms to achieve both regenerative and ecological outcomes.

3. Conclusions

The overall conclusions from the articles featured in this thematic issue is the overriding and increasing importance of good quality GI. The articles feature research undertaken in the northern and southern hemispheres—e.g., Europe, Australia, and North America—which is testament to the global significance of the topic. In 2020, humankind has experienced the Covid-19 pandemic, with most people working from home and restricted from going out for extended periods and limited to travelling only a few kilometres from home. This substantial change of lifestyle has increased the importance, consciousness, and relevance of GI globally. People are much more aware of local parks and green space as places for safe interaction with nature and other people, albeit at a distance.

This issue is themed around evidence for embedding ecology into decision-making. Four essential stages are recognized, which are to conserve, manage, enhance, and create (Davies et al., 2017). There are five key ways in which we can deliver these essential stages. First, in policy we should protect. Protecting existing GI, particularly urban tree canopy, avoids losses that invariably takes years to recover. Well drafted planning policy is an effective means of protection. Second, and again emerging from a policy framework, is the development and adoption of tools such as Melbourne's Green Factor tool. These tools provide a robust approach for stakeholders to develop and adopt transparent benchmarks. From these benchmarks, management, enhancement, and creation of GI is possible. The third key conclusion is the need to *value* GI, and to communicate and educate the community about the various social, economic, and environmental values of GI and their respective benefits. The outcomes of education and communication are increased requests for GI and appreciation of its values. The fourth conclusion is the vital role of planners and professional bodies in raising awareness, designing and implementing policies, and updating and broadening education programs to reflect the vital role of GI in sustainable, liveable, resilient urban development. Through their efforts it will be possible to increase delivery of GI. Finally, the concept of regenerative design is posited, whereby GI is a vital ingredient to deliver urban development with positive GI and its associated benefits of better air quality, increased habitat for biodiversity, biophilic engagement of human populations, moderation of the urban heat island, attenuation of stormwater flow, and where placed near or on buildings, reductions in energy used in heating and cooling. In summary, the articles provide ample evidence for embedding ecology into decision-making to deliver the improved GI-rich urban developments which are desperately needed.

So, where to in the future? The term 'megatrends' has propagated through both the academic and popular literature since the publication of John Naisbitt's (1982) book of that name. It is worth a brief excursion into potential megatrends affecting urban GI: Some of these are addressed in this collection of articles, some are not. Coronavirus has underscored the *salutogenic* (Antonovsky, 1979) function of urban GI, in terms of both physical and mental health. Whether contributing to stress reduction or facilitation of active transport, rapid urbanisation will ensure this aspect continues to expand. And as our cities grow, the abundant potential of *urban agriculture* as a GI type is becoming increasingly evident. The rising importance of *digital technologies* such as GIS, remote sensing, big data, and the internet of things allow us to conserve, manage, enhance, and create GI and ever more efficiently and effectively integrate it into our urban human habitat. Further, as we grasp the challenge of dwindling natural resources and the need for circularity to replace linearity in economic management, the application of *life cycle thinking* to urban GI—supported by the above digital technologies—will underpin application of new methods to enable the transition from sustainable to *regenerative* policy, planning, and practice. Last but certainly not least will be the increasing role of GI in *cooling our overheating cities*.

Acknowledgments

We gratefully acknowledge the help and support of the *Urban Planning* editorial staff in preparing this thematic issue.

Conflict of Interests

The authors declare no conflict of interests.

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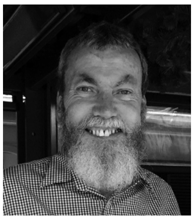

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COGITATIO

Urban Planning (ISSN: 2183–7635)
2021, Volume 6, Issue 1, Pages 5–19
DOI: 10.17645/up.v6i1.3481

Article

Trade-Offs between Urban Green Space and Densification: Balancing Outdoor Thermal Comfort, Mobility, and Housing Demand

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Submitted: 15 July 2020 | Accepted: 23 September 2020 | Published: 26 January 2021

Abstract
Urban green spaces reduce elevated urban temperature through evaporative cooling and shading and are thus promoted as nature-based solutions to enhance urban climates. However, in growing cities, the supply of urban green space often conflicts with increasing housing demand. This study investigates the interplay of densification and the availability of green space and its impact on human heat stress in summer. For the case of an open-midrise (local climate zone 5) urban redevelopment site in Munich, eight densification scenarios were elaborated with city planners and evaluated by microscale simulations in ENVI-met. The chosen scenarios consider varying building heights, different types of densification, amount of vegetation and parking space regulations. The preservation of existing trees has the greatest impact on the physical equivalent temperature (PET). Construction of underground car parking results in the removal of the tree population. Loss of all the existing trees due to parking space consumption leads to an average daytime PET increase of 5°C compared to the current situation. If the parking space requirement is halved, the increase in PET can be reduced to 1.3°C–1.7°C in all scenarios. The addition of buildings leads to a higher gain in living space than the addition of floors, but night-time thermal comfort is affected by poor ventilation if fresh air circulation is blocked. The protection of mature trees in urban redevelopment strategies will become more relevant in the changing climate. Alternative mobility strategies could help to reduce trade-offs between densification and urban greening.

Keywords
densification; ENVI-met simulations; green infrastructure; outdoor thermal comfort

Issue
This article is part of the issue "Urban Planning and Green Infrastructure" edited by Paul Osmond (University of New South Wales, Australia) and Sara Wilkinson (University of Technology Sydney, Australia).

1. Introduction

In the past decade, green and blue spaces in cities have been promoted as no or low regret adaptation measures to climate change (European Commission, 2016). Bodies of water and vegetated areas regulate air temperature (T_a) and radiative heat load and thus improve outdoor human thermal comfort through evaporative cooling and shading (Bowler, Buyung-Ali, Knight, & Pullin, 2010). Among these, trees are the most effective in reducing incoming shortwave radiation (Erell, 2017; Zölch, Maderspacher, Wamsler, & Pauleit, 2016). Dense, foliated tree crowns reduce the transmissivity of direct solar radiation to 1%–5% (Konarska, Lindberg, Larsson, Thorsson, & Holmer, 2014), reducing daytime T_a by up to 3°C, the mean radiant temperature by up to 37°C and the physical equivalent temperature (PET) directly beneath the tree crown by up to 16°C (Lee, Mayer, & Kuttler, 2020). However, ongoing urbanisation and population growth lead to high pressure on open spaces in cities. Therefore, urban areas undergoing densification by the addition of buildings or the increase in the size of existing buildings often exhibit a lack of urban green space (Haaland & van den Bosch, 2015).

Reduced amounts of green space, an increase of impervious surfaces, altered albedo and geometry are all contributing factors to the Urban Heat Island phenomena (Oke, 1982). Such infill development is likely to further increase urban heat load, exacerbating existing outdoor heat stress (Emmanuel & Steemers, 2018).

Confronted with the need to meet the housing demand on one hand and the challenge to adapt cities to climate change on the other, city planners require information about the effects of densification on urban microclimate, green space availability and its ecosystem services. The factors that influence urban climate and urban heat have been studied from the city level (e.g., Akbari & Kolokotsa, 2016; Deilami, Kamruzzaman, & Liu, 2018) to the neighbourhood scale (Pacifici, Marins, Catto, Rama, & Lamour, 2017) and single urban facets (e.g., Jamei & Rajagopalan, 2018; Lee et al., 2020). While climate adaptation planning needs to adopt a multiscale perspective to address the Urban Heat Island as well as local thermal hotspots (Demuzere et al., 2014), the microclimatic level is the reference scale for outdoor human thermal comfort investigations (Hirashima, Katzschner, Ferreira, Assis, & Katzschner, 2018; Mayer & Höppe, 1987). The urban layout and geometry, as well as abundance of vegetation, are some of the most important parameters governing urban microclimate and outdoor thermal comfort (Erell, Pearlmutter, & Williamson, 2011; Jamei, Rajagopalan, Seyedmahmoudian, & Jamei, 2016). Altered aspect ratios and sky view factors affect the short- and long-wave radiation as well as the wind speed (Erell et al., 2011). For instance, higher aspect ratios due to taller buildings are likely to lead to lower daytime and higher night-time air temperature (Jamei et al., 2016). Wide E–W oriented streets are more prone to thermal discomfort than narrow and N–S oriented street canyons due to longer times of solar exposure (Ali-Toudert & Mayer, 2006); thus vegetation plays an important role, especially for E–W oriented streets (Sanusi, Johnstone, May, & Livesley, 2016).

Differing from these studies that concentrate on single urban street canyons, other investigations have compared city quarters with different amounts of vegetation, built area coverages and building heights (Yahia, Johansson, Thorsson, Lindberg, & Rasmussen, 2018) or have altered these characteristics for a specific setting to study their micrometeorological impacts (Perini & Magliocco, 2014). Yahia et al. (2018) found the strongest relationship (R^2 0.97) to be between sky view factor and PET at 2 pm, and shading to be more important than ventilation. Simultaneously increasing the building height and the green coverage provided the best thermal comfort for pedestrians (Lee et al., 2020; Perini & Magliocco, 2014). In this regard, increasing building height is preferred over increasing built area coverage (Emmanuel & Steemers, 2018); however, in these studies green coverage was rather treated as a quantitative parameter with disregard of the impact of densification on the qualities of the existing vegetation. Investigating nature-based solutions in a densely built-up area, Zölch et al. (2016) emphasised that the qualities of urban greening and the placement of street trees have a decisive influence on outdoor thermal comfort. The effects of densification on existing vegetation were not investigated. In their review of challenges and strategies for densifying cities, Haaland and van den Bosch (2015) noted that there is a lack of studies that consider the interplay of urban infill and the qualities of the existing green space, as well as the planning advice to deal with both.

In reference to the microscale, the aim of this study is therefore to answer the following research questions: i) How is urban green space (especially urban trees) affected by densification and what are the consequences for human heat stress? ii) How can the trade-offs between densification and greening be effectively minimised? Based on an actual planning case in the city of Munich (Germany), we compare different development scenarios to quantify the effects of densification on the existing green space and human heat stress. In a first step, we derive key parameters for the development of realistic densification scenarios by planning in exchange with city planners. Second, we create densification scenarios that portray different planning options for the open midrise redevelopment area. Finally, micrometeorological simulations (ENVI-met model) are carried out to compare the densification alternatives with the current situation and to discuss the implications for urban planning.

2. Study Area

Munich, located in the south of Germany (48°8'N, 11°24'E, elevation 519 m a.s.l.), is one of the fastest-growing cities in Germany and is expected to reach 1.85 million inhabitants by 2035 (Landeshauptstadt München, 2011). With an annual average T_a of 9.7°C and an average precipitation of 944 mm (reference period 1981–2010; German Meteorological Service, 2018), Munich's climate corresponds to the Cfb category of the Köppen-Geiger classification. The characteristics of the city's climate include warm summers, an absence of dry seasons and highest precipitation rates during the summertime (Mühlbacher, Koßmann, Sedlmaier, & Winderlich, 2020).

While housing demand in Munich is high (according to an estimate, there is an annual requirement for the building of 8,500 flats per year; Landeshauptstadt München, 2011), the potential for the development of new residential areas outside the city and through the conversion of disused land has become scarce. One of the city's strategies for dealing with this scarcity is "qualified densification" in the stock (Landeshauptstadt München, 2011). This is especially the case with housing estates from the 1950s to the 1980s, which account for a quarter of all residential areas in Munich and offer great potential for gaining new residential space. The urban redevelopment area in Munich's city district, Moosach, is characterised by free-standing multistorey blocks from the 1950s. Free-standing multistorey blocks have a high potential for densification due to the presence of generous green spaces and, often, uniform ownership structures, that simplify planning and communication processes. Furthermore these multistorey blocks represent one of the most common building types in Munich (Pauleit & Duhme, 2000) and, more generally, in German cities (Zentrum für Stadtnatur und Klimaanpassung, 2017). The study area comprises 10-row buildings with pitched roofs of 14 m in height (four floors including the attic floor; Figure 1). There are large green spaces between the building rows—some with a high tree cover, some rather open—that result in a vegetation cover of 50%. Thus, the area can be characterised as local climate zone 5 (open midrise). Local climate zones represent universal climate-based classifications of urban and rural sites that share similar characteristics regarding surface cover, building structure, materials and human activity (Stewart & Oke, 2012).

A particular challenge for developing green and dense city quarters in Munich lies in providing sufficient car parking space. According to Bavarian planning regulations, one parking space has to be provided for each residential unit (Art. 47 BayBO). Based on a resolution by the City Council of Munich, this ratio can be reduced when access to public transport and local amenities is sufficient or in the case of subsidised residential construction. To do so, a profound mobility concept has to be provided, in which required criteria and alternative mobility solutions have to be stated. Reductions below a 0.8 ratio require extensive compensation measures, while 0.3 represents the maximum reduction ratio (Landeshauptstadt München, 2020).

3. Methodology

3.1. Development of Densification Scenarios

To gain insights in current planning policy into Munich and to derive realistic densification scenarios, we investigated all the local plans that have come into force in recent years (1 January 2014–28 March 2019). Local plans are legally binding planning instruments that concretise the possible use of a certain area and provide guidelines for possible structural development. Since inner-city development and residential areas were particularly of interest for this study, we excluded all the local plans relating to outdoor, special and industrial areas from further analysis (25 out of 60 plans). The remaining 35 plans were categorised regarding their location, type of development, permissible floor space and floor area, building height, planned residential units and plan layouts. Of further interest were the regulations dealing with parking space and green space provision.

Figure 1. Spatial assignment of investigation area. Location of the city district Moosach within Munich (a); map of the study site's wider neighbourhood (b); aerial image of the study site (c); row buildings and the middle street in the study site (d). Source: Sabrina Erlwein (with basic geographical data provided by the Bavarian State Office for Survey and Geoinformation 2018).

Although most of the areas were well connected to transport nodes and thus qualified for a parking space reduction, the ratio of parking spaces per residential unit was reduced from 1 to 0.6 only in three out of 35 local plans. Moreover, in 91.5% of the plans analysed, the required parking spaces had to be provided by underground car parks. The areas designated for underground parking usually extended over the entire green space between the buildings. Therefore, parking space provision was identified as one key parameter affecting green space provision.

Additionally, four workshops were held with city planners involved in the redevelopment of the study area (24 June, 25 July, 10 October, 16 December 2019). The participants included personnel from the Department of Urban Planning and Building Regulations (overall project management and green planning) and the Department of Health and Environment (climate change mitigation and adaptation). While the first two meetings focussed on planning challenges and goals for the development area and identification of key parameters for densification, the last two were used to discuss and refine the developed densification scenarios.

The scenarios are distinct by i) type of densification, ii) building height and iii) number of underground car parks (Figure 2). The category 'type of densification' distinguishes between the addition of floors, in which the buildings' free-standing form is retained (O = open blocks), and the addition of buildings, whereby the existing buildings are closed alongside the road (C = closed rows). The building height varies between one and two additional floors (in total 15/18 m). Furthermore, we varied the number of underground car parks (a = 1, b = 4, c = 8) to reflect the different parking space policies. For instance, the additional housing units gained by adding one floor (Table 1) could be supplied by the existing underground car park (a), if the parking space key was reduced to 0.3. If the current regulation was applied or if the ratio was even increased, four (b) or more (c) underground car parks would be necessary. The construction of underground car parks causes the removal of existing trees from the designated areas. In case b (four

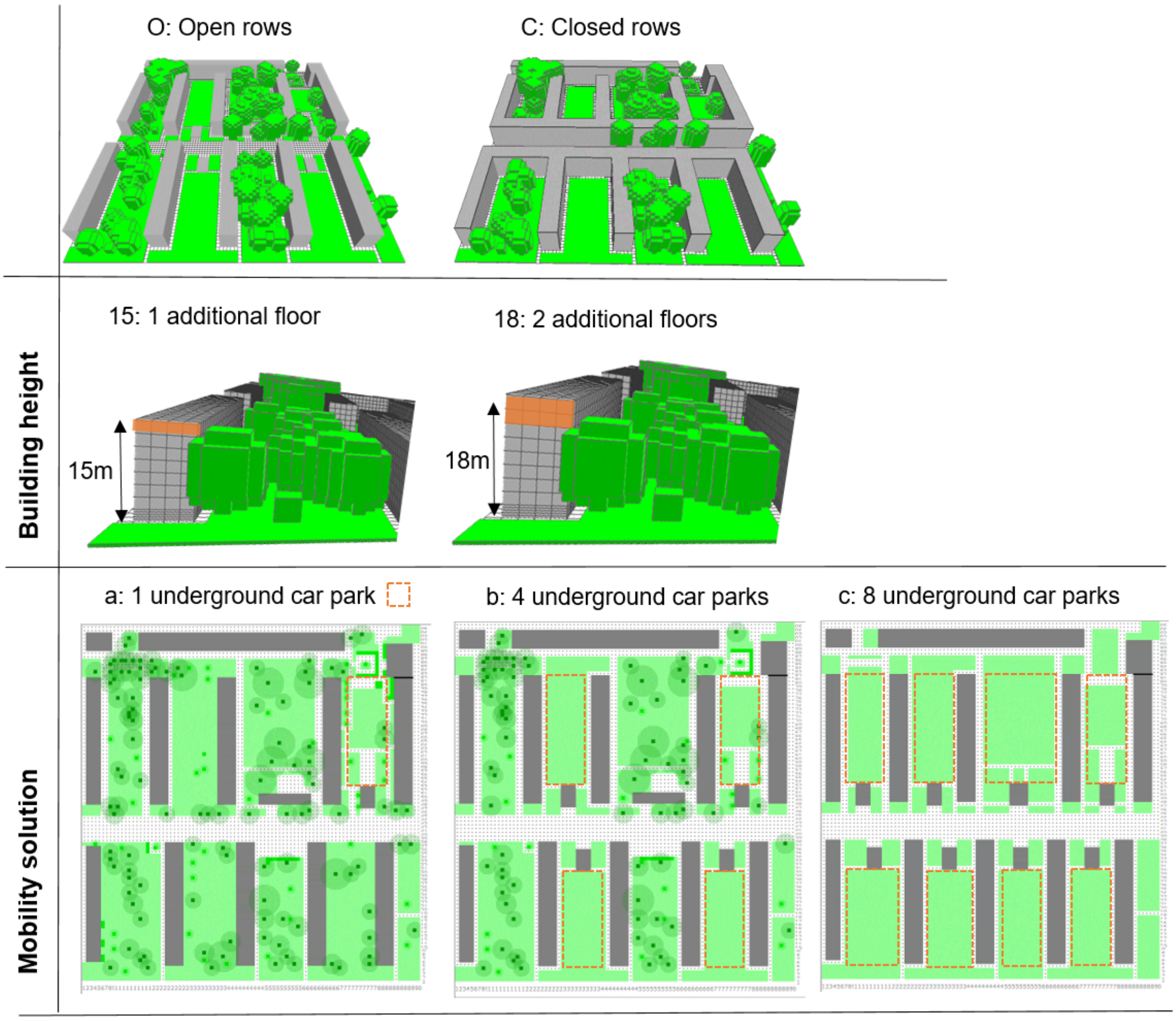

Figure 2. Scheme for all densification scenarios with basic categories of densification type, building height and mobility solution; locations of underground car parks are marked with dashed lines. Source: Sabrina Erlwein.

Table 1. Overview of the basic parameters of the densification scenarios.

Scenario	Built surface	Floor area ratio	Building height	Number of trees	Number of flats*	Underground parking
Status Quo	24.1%	0.8	13 m**	158	376	1
O15a	24.1%	1.3	15 m	158	427	1
O15b	24.1%	1.3	15 m	102	427	4
O15c	24.1%	1.3	15 m	0	427	8
C15b	31.1%	1.7	15 m	84	552	4
C15c	31.1%	1.7	15 m	0	552	8
O18b	24.1%	1.6	18 m	102	512	4
O18c	24.1%	1.6	18 m	0	512	8
C18c	31.1%	2.5	18 m	0	663	8

Notes: * = Calculation of flats: Current status 46,5 m^2 per flat, after redevelopment 67,5 m^2 per flat; ** = Saddle roof

underground car parks), the underground car parks were preferably assigned to lawns with a few trees to preserve as many trees as possible.

Further modification of supply of greenery included the removal of all the trees that were closer than 4 m to the buildings since they would not survive the construction works. The name of the scenario indicates the parameters used (e.g., O15b = open rows, 15 m height and four underground car parks). Since the chosen scenarios reflect planning scenarios, not all twelve conceivable combinations were simulated but only those that could occur in reality. For instance, in the case of the most extreme densification (C18), parking demand triggered by new flats would be too high to be covered by just four underground car parks, thus only scenario C18c was simulated. To calculate the number of new apartments for each scenario, we used actual data from the housing association. After the renovation, the living space per residential unit would increase from the current 46.5 to 67.5 m^2.

3.2. Urban Micrometeorological Simulation Model ENVI-Met

All simulations in this study were performed with the three dimensional microscale model ENVI-met (Bruse & Fleer, 1998; Simon, 2016), version 4.4.3. ENVI-met is one of the most widely used simulation tools, being successfully applied in various contexts and geographical zones for micrometeorological investigations (Tsoka, Tsikaloudaki, & Theodosiou, 2018). ENVI-met considers complex interactions of building structures, atmosphere, soil and vegetation processes (Simon et al., 2018), with a typical resolution of 0.5–10 m in space and up to 2 s in time. Numerous studies have assessed the model's accuracy and have testified it to be well suited to outdoor comfort investigations, especially during daytime (Acero & Arrizabalaga, 2018; Lee, Mayer, & Chen, 2016). The ENVI-met application BIOMET allows the calculation of several thermal comfort indices, such as Universal Thermal Comfort Index and PET. The PET was chosen for this study as it is adapted for outdoor settings (Mayer & Höppe, 1987), constitutes one of the recommended thermal comfort indices for human bio-meteorological investigations (Staiger, Laschewski, & Matzarakis, 2019), and is frequently used and thus further developed (Hirashima et al., 2018). In a recent calibration for the German cities Kassel and Freiburg, PET values above 35°C were perceived as hot and PET values above 38°C as very hot (Hirashima et al., 2018), while Holst and Mayer (2010) suggest a PET transition value of 35°C toward warm and 40°C toward hot based on investigations in Freiburg. Recently, Zölch, Rahman, Pfleiderer, Wagner, and Pauleit (2019) evaluated the model performance of ENVI-met for Munich and found an underestimation of T_a during the evening hours of 1.0–1.5 K. However, the overall model performance was found to be satisfactory (R^2 of 0.94). Therefore ENVI-met is regarded as a suitable micrometeorological investigation tool for this study.

3.3. Model Configuration and Meteorological Input Data

The required meteorological data for the ENVI-met simulation were extracted from the weather station of the German Meteorological Service, City-Station ID 3379, located approximately 2.8 km from the study area. The weather data for the past 10 years were analysed to select two running days (4 and 5 of July 2015) that representes typical hot days. Hot days are characterised by daytime maximum T_a above 30°C and a nightly T_a not below 20°C, with clear skies and low wind speed (up to 2 m/s; Mühlbacher et al., 2020). This focus was chosen as the number and intensity of hot days is likely to increase due to climate change (Mühlbacher et al., 2020). Heat stress negatively affects human health leading to a lack of concentration, exhaustion, dehydration, heat stroke, hyperthermia and eventually death (Ward Thompson, Lauf, Kleinschmit, & Endlicher, 2016). ENVI-met version 4.4.3 allows full forcing of wind speed and wind direction. However, if the wind direction changes too fast, the simulation is aborted. Thus, the most common wind direction for each hour during summertime was statistically identified based on the German Meteorological Service weather station data (1985–2018) and used as model input.

A figure presenting all the meteorological input variables can be found in S1 of the Supplementary File.

The chosen horizontal and vertical resolution of 2 × 2 m represents a compromise between sufficient geometric detail and sufficient computational speed (Zölch et al., 2016). For higher accuracy of surface interactions, the lowest vertical cell was further divided into five sub-boxes. The grid was rotated 32° from the north to rectify the building structure. The building heights and dimensions were derived from the GIS-Data provided by the City of Munich. The pavement and building materials were identified by visits to the site (for configuration details see Table 2).

Recent tree inspection data (including tree species, tree height and crown dimensions) from the municipal company were available for most of the study area. The data were supplemented by on-the-spot visits to include missing trees and to identify unclear tree locations. Out of 158 trees, 27 different tree species were identified in the study area and were sorted into five different categories for the sake of simplification. As the main cooling effect of trees is attributed to shading (Erell et al., 2011), the focus was set on tree characteristics that influence the reduction of radiation load, namely tree height, canopy shape and foliage density (Rahman, Stratopoulos et al., 2020). Based on the inspection data and on definitions of the City of Munich from local plans, we defined three different tree heights (small = 6 m, medium = 15 m, large = 22 m), into which the existing trees were classified. The crown height to diameter ratio was calculated for each tree to sort it into either spherical or cylindrical crown form. However, all the small trees were grouped into one category since differences among their crown shapes were small. ENVI-met uses the leaf area density (LAD) to define the foliage density. The LAD values of predefined species in ENVI-met's tree manager Albero range from 0.4 (populus alba) to 2.0 (e.g., acer platanoides). For new tree configurations, Albero offers LAD 0.3 m^2/m^3 and LAD 1.1 m^2/m^3 as standard values. Since foliage density also varies within species due to the growing season and the tree's age (Rahman, Stratopoulos et al., 2020), which complicates representation by categories and tree parametrisation not being the aim of this study, the medium LAD of 1.1 m^2/m^3 was chosen for all tree categories. The final five tree categories including their parameters are presented in Table 3.

Simulations were launched at 6 am for a total model time of 48 hours (Table 2). We excluded the first 24 hours from the analysis to overcome initial transient conditions. Simulation outcomes were analysed for the hottest (2 pm) and coolest hour (4 am), to detect possible trade-offs between daytime and night-time at a pedestrian level of 1.4 m height (approximating to the human-biometeorological reference height; Mayer & Höppe, 1987). In addition, we computed and mapped the averages from 10 am to 4 pm to better depict the design parameters' influence on the shadow cast during the day (Holst & Mayer, 2011). Compared to an analysis of just one point in time, this makes it possible to derive more robust design implications (Lee et al., 2016).

Table 2. ENVI-met model setup and meteorological input data.

Start of simulation	4 July 2015, 6 am
Duration of simulations	48 h
Modell grid size/resolution	90 × 95 × 25/2 × 2 m
Building materials	Brick (wall), tile (roof)
Wind speed (10 m above ground)	0.7 m-s–2.0 m/s
Wind direction	240°–310°
Max/min T_a	35.4°C/21.7°C
Cloud cover	cloud-free
Lateral boundary conditions	Full forcing
Initial soil temperature	Upper layer (0–0.2 m): 23.85°C, middle layer (−0.5 m): 23.9°C, deep layer (−2 m): 19.9°C
Relative soil humidity	Upper layer: 50%; middle and deep layer: 60%

Table 3. Tree categories used in the ENVI-met simulation (base case).

Category	Size	Height	Diameter	LAD	Count
K1	Small (all forms)	6 m	5 m	1.1	44
K2	Medium, spherical	15 m	11 m	1.1	19
K3	Medium, cylindrical	15 m	9 m	1.1	50
K4	Large, spherical	22 m	17 m	1.1	12
K5	Large, cylindrical	22 m	11 m	1.1	34

4. Results

4.1. Comparison of Day-Time Thermal Comfort for the Current Situation and Densification Scenarios

Simulation results for the current situation reveal overall very hot thermal conditions for pedestrians at 2 pm (Figure 3). Nearly 100% of the study area experiences extreme heat stress (PET mean value of 46.9°C). The coolest locations were found in the shadows of trees and buildings (PET 41°C–43°C), whereas the thermal hotspots were found in front of the sun-facing façades (SE orientation) and the poorly ventilated areas (PET 55°C–56.6°C). This pattern was mainly attributed to the impact of solar radiation as expressed by the mean radiant temperature. On cloudless summer days, the mean radiant temperature is the dominating factor for outdoor human thermal comfort in Central Europe (Ali-Toudert & Mayer, 2007; Holst & Mayer, 2011; Lee & Mayer, 2018). All densification scenarios except for scenario O15a, were, on average, hotter than the base case. In scenario O15a, the buildings were raised by one storey, but the existing vegetation was completely preserved. There, the full tree canopy combined with the additional shadow cast from the elevated buildings further reduced the short-wave radiation densities and thus improved the thermal comfort compared to the base case. The impact of additional underground car parks becomes visible in the remaining scenarios: The higher the number of removed trees, the greater the penetration of solar radiation and the higher the median PET (Figure 4a). Remarkably, at noon the median difference between 100% trees and 65%–53 % trees is larger than that between the latter and zero trees (PET median difference of 2.0°C–2.1°C compared to 0.5°C–0.6°C). However, while in scenarios with 65%–53% trees, 75 % of all locations were cooler than 50°C (PET), nearly half of the study area in the tree-less scenarios was hotter than 50°C (PET; Figure 3, Figure 4). The variety of cooler and hotter grid cells is higher in scenarios with trees (PET interquartile range of 5.9°C–5.4°C to 3.2°C–1.3°C) but also in scenarios with a more closed building arrangement compared to the default arrangement of free-standing blocks. Building heights have only a marginal impact on noon simulation outcomes.

The closure of the building rows has two opposing effects: On the one hand, the newly introduced buildings shade one side of the street and a portion of the northern

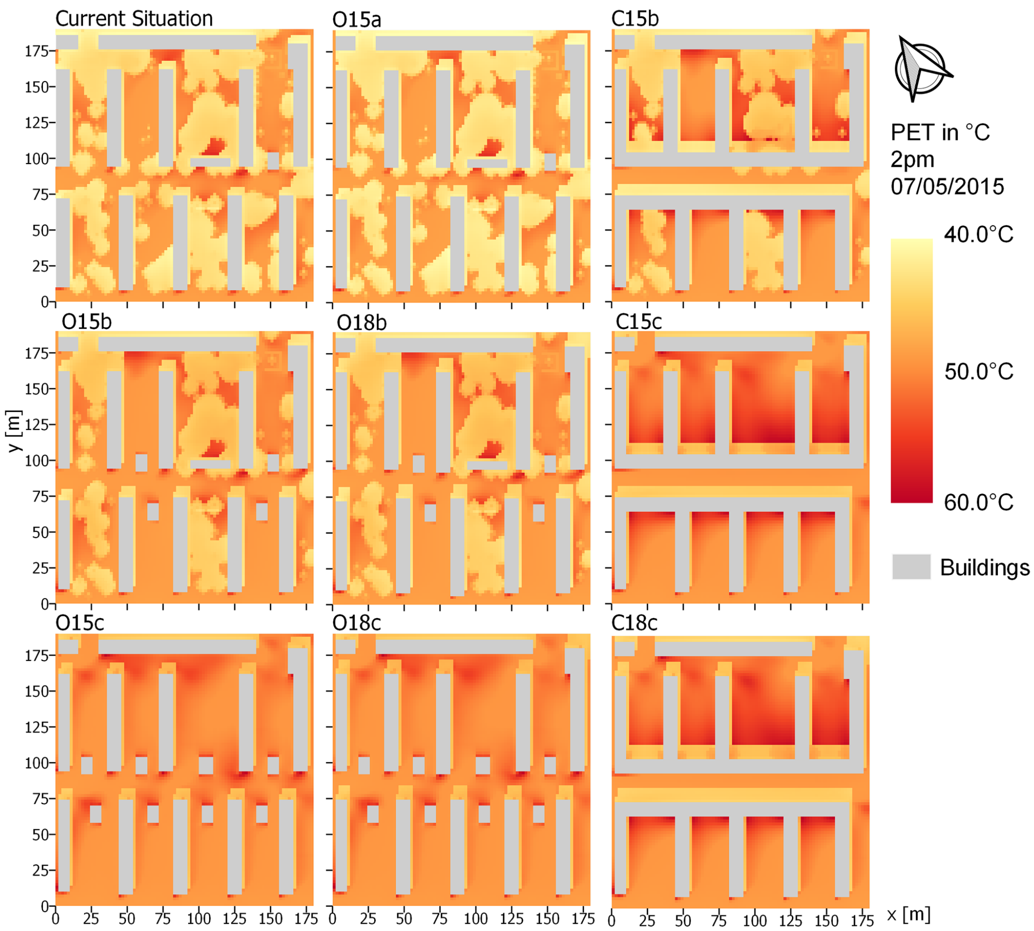

Figure 3. Simulated PET values at 2 pm on 5 July 2015 for the current situation and the eight densification scenarios (1.4 m height). Notes: O = open rows, C = closed rows; 15/18 = 15/18 m building height; a/b/c = 1/4/8 underground car parks. Source: Sabrina Erlwein.

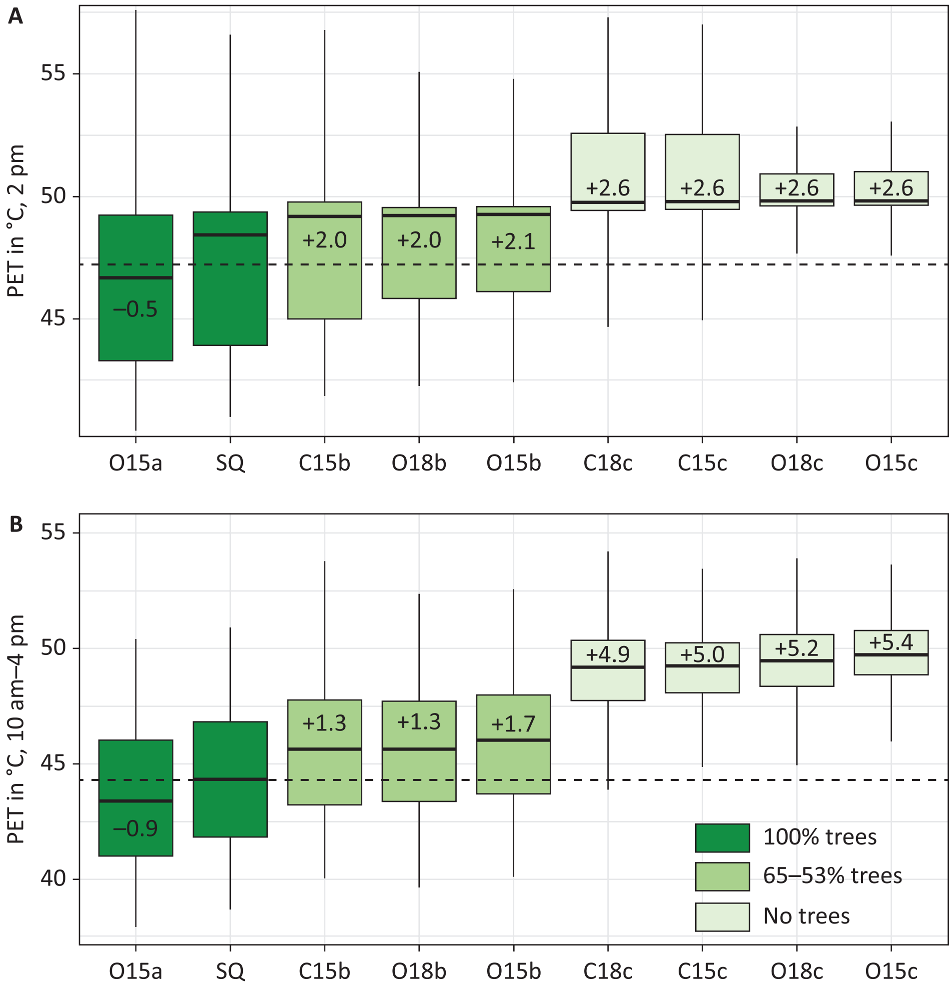

Figure 4. Boxplots of the PET values for all densification scenarios at 2 pm (A) and 10 am–4 pm (B) on 5 July 2015. The colours refer to the number of trees in the respective scenario. The dashed line marks the median value of the current situation; the numbers in the boxes indicate the respective deviation from the base case (= SQ) median. Source: Sabrina Erlwein.

yards. On the other hand, heat accumulates especially in the northern yards, enlarging the total area with PET values above 51°C to nearly 40% (compared to 7% in the current situation and 23%–25% in the open row simulations; see S2 of the Supplementary File). At the same time, wind speed in the enclosed yards is—0.6 m s-1 lower compared to the open row configuration, whereas elevated wind speed in the middle street indicates a channelling effect (Figure 5).

If not only the hottest hour, but the time period from 10 am to 4 pm is considered, the contrast between 100% (category c) and 50% (category b) tree removal becomes more prominent (Figure 4, A). The removal of all existing trees leads to an increase in average PET by 4.9°C–5.4°C compared to the current situation. This increase can be considered as a significant deterioration of thermal comfort under a human-biometeorological perspective. In contrast, average increase in PET is reduced to 1.3°C–1.7°C if only half of the trees are removed. While the largest differences in thermal comfort are again attributed to the presence of trees and their blocking of direct solar radiation, higher building heights result in slightly lower PET temperature averages (0.1°C–0.4°C), both for the open row and closed row configuration. This is because higher buildings cast more shadows and thus reduce the mean radiant temperature. The hottest overall thermal conditions are observed for scenario O15c, without trees, open rows and lower building heights, while scenario O15a (all trees preserved) is the coolest one. For the spatial distribution of PET values, see S4 of the Supplementary File.

4.2. Comparison of Night-Time (4 am) Thermal Comfort for the Current Situation and Densification Scenarios

In contrast to the daytime situation, in the early morning (4 am) green spaces with high tree cover are slightly warmer (+0.9°C for PET) than only grassed areas. Tree canopies reduce the amount of out-going longwave radiation and retain daily heat, while high sky view factors are beneficial for nocturnal cooling. The warmest spots are located in the vicinity of NE oriented building facades, whereas non-disclosed areas are the coolest ones (Figure 6). The PET averages 18.8°C for the base

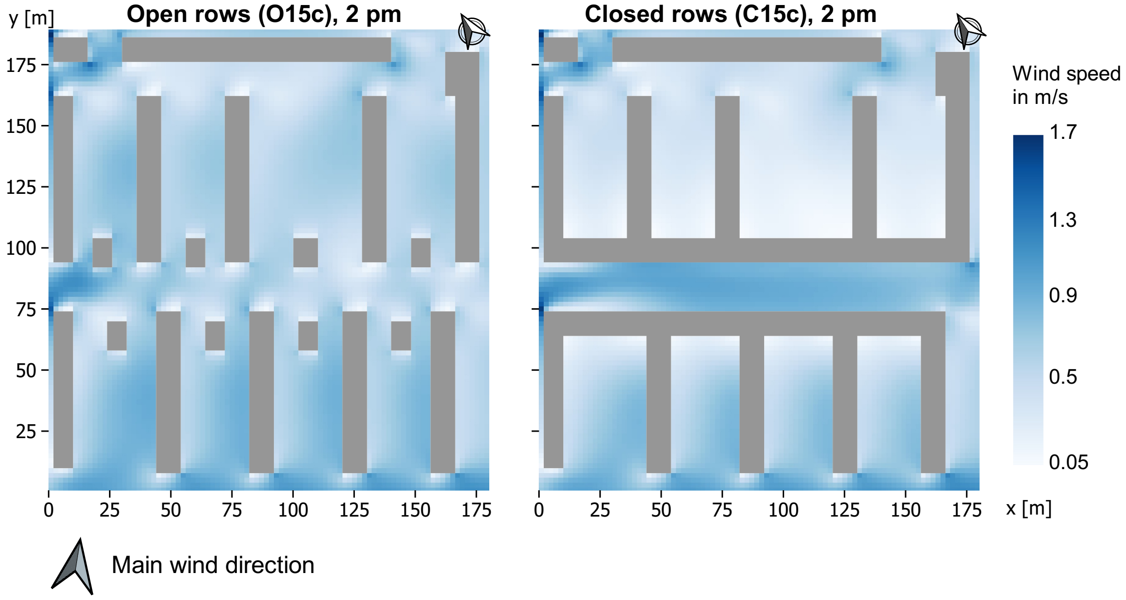

Figure 5. Wind speed at 1.4 m height for two different building configurations without trees on 5 July 2015. Source: Sabrina Erlwein.

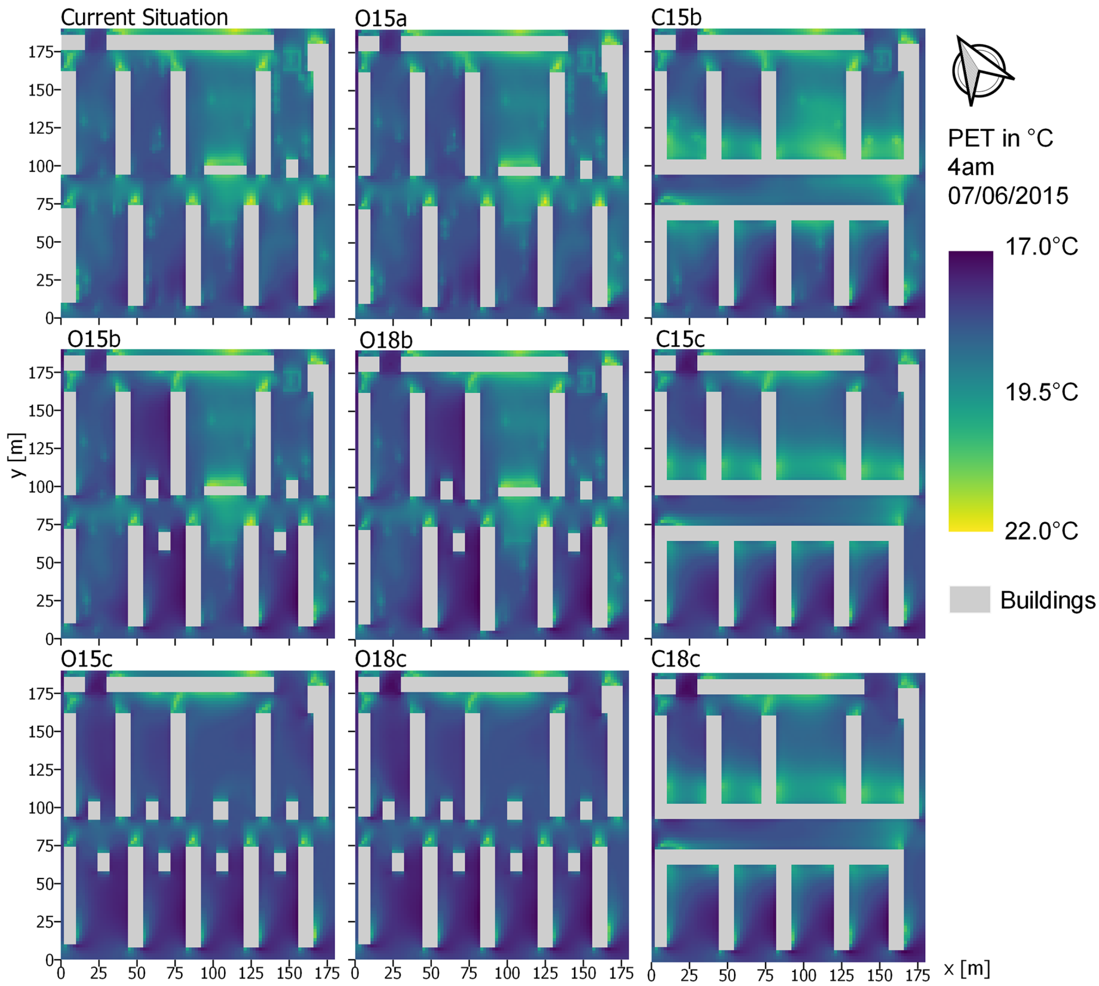

Figure 6. Simulated PET values at 4 am for the current situation and the eight densification scenarios (1.4 m height). Notes: O = open rows; C = closed rows, 15/18 = 15/18 m building height, a/b/c = 1/4/8 underground car parks. Source: Sabrina Erlwein.

case (Figure 7). In the absence of solar radiation, the PET range between the warmest and the coolest spot is just 4.1°C PET (and 0.8°C for T_a). Only scenario C15b (closed rows, trees in every 2nd courtyard) is on average warmer (+0.1°C for PET) than the current situation (Figure 7). However, differences in average PET are small (18.4°C to 18.9°C). Unlike during the day, the number of trees and the sky view factor in the respective set-up are not the most influential factors for thermal comfort. Instead, building arrangements with open rows that permit infiltration of airflow are cooler than the 'closed rows' design scenarios. Similar to the daytime observations, the northern courtyards are more affected by an elevated temperature than the southern ones (18.7°C vs 20.0°C for PET). In the warmest scenario, combining closed rows with longwave radiation retaining tree canopies (C15b), 45% of the area is warmer than 19°C, while it is 12% for the coolest scenario O18c (open rows, no trees; S3 of the Supplementary File). Higher buildings heights are associated with a lower overall PET.

For side-by-side comparison of all the modelling results for daytime and night-time, Figure 8 depicts the average PET deviations of all the densification scenario outcomes from the current situation.

5. Discussion

When comparing eight densification scenarios for an urban redevelopment site, preservation of the existing vegetation was identified as the most important parameter in reducing diurnal outdoor heat stress. All treeless scenarios were significantly hotter regardless of densification type and building height, followed by those scenarios featuring a reduced amount of vegetation. These findings are in line with other studies that identified trees as being the most efficient in heat mitigation due to their shading potential (Chatzidimitriou & Yannas, 2016; Erell, 2017; Lee et al., 2016;). Open spaces with high sky view factors cool down faster during the night-time as heat dissipation is not hindered by obstacles (Erell et al., 2011). Tree canopies trap radiant heat at night, retaining daytime heat (Bowler et al., 2010). Thus, most of the densification scenarios are hotter during daytime and cooler during night-time, due to their reduced number of trees; however, free flows of cooling wind are equally important. The four coolest scenarios at 4 am were those with open row buildings as south-westerly airflow can penetrate into the green spaces between the buildings. With closed rows, these wind flows are blocked (reducing wind speed by 0.6 m/s), this being especially detrimental for the northern courtyards. There, night-time PET (4 am) is up to 2.0°C warmer and daytime PET (2 pm) is as much as 4.8°C–6.8°C warmer.

While a large number of studies have shown how adding green infrastructure can help to mitigate increased summer temperature (Lee et al., 2016; Perini & Magliocco, 2014; Zölch et al., 2016), this study stresses that preservation of fully grown and high quality green infrastructure elements in urban redevelopment sites is equally important. The cooling capacity of trees is not uniform, but depends on tree species, growing conditions (Rahman, Moser, Rötzer, & Pauleit, 2019), geographical location, season (Jamei et al., 2016), placement of trees and individual tree parameters (e.g., tree height, healthiness; Rahman, Stratopoulos et al., 2020). In fact, several authors argue that a lower number of urban green spaces in growing cities might be substituted by improving their quality (Artmann, Inostroza, & Fan, 2019; Haaland, & van den Bosch, 2015). Similarly, a loss of urban green space might be acceptable if the

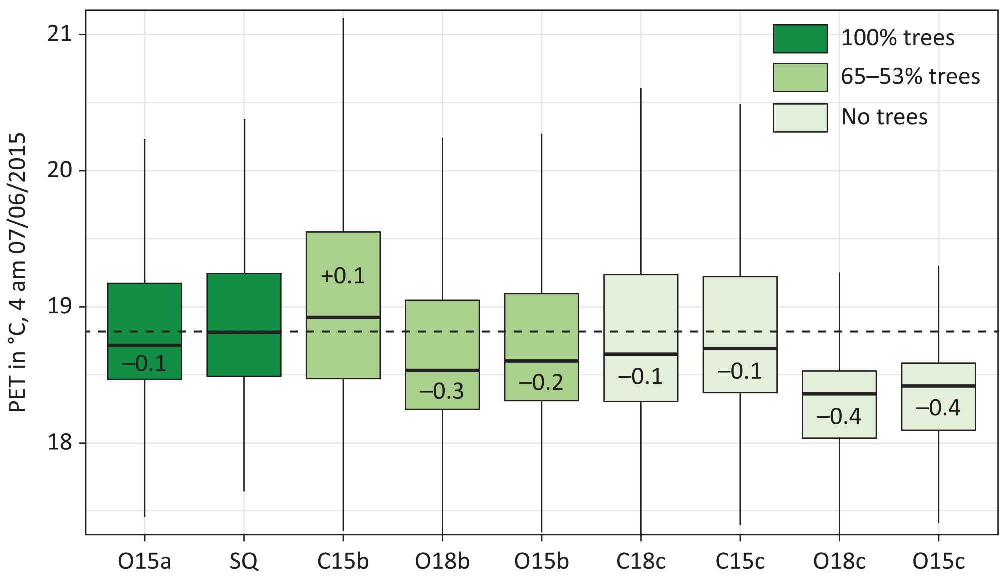

Figure 7. Boxplots of PET values for all the densification scenarios at 4 am on 5 July 2015. Notes: The colours refer to the number of trees in the respective scenario. The dashed line marks the median value of the current situation; the numbers in the boxes indicate the respective deviation from the base case (= SQ) median. Source: Sabrina Erlwein.

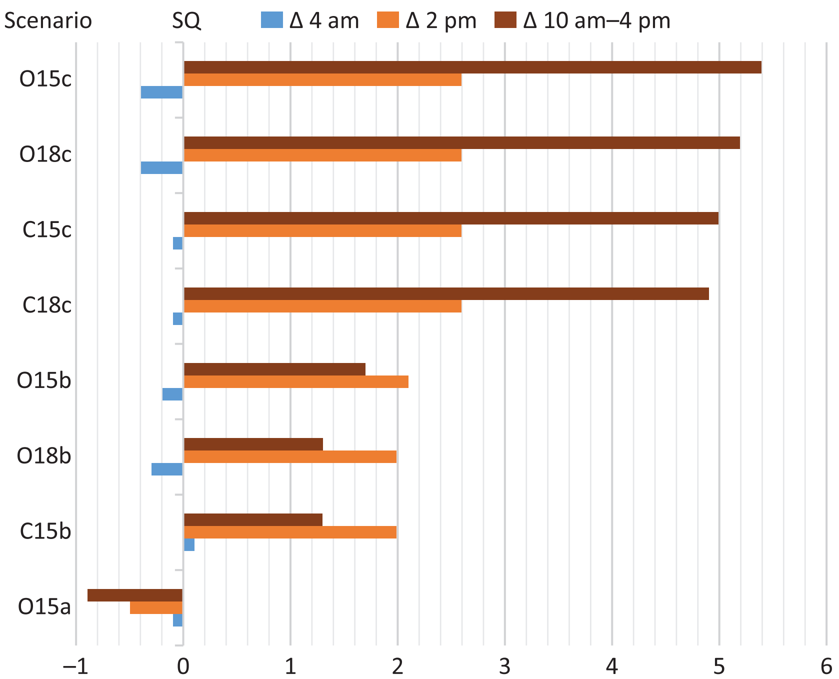

Figure 8. Deviations (in °C) from the average PET of the current situation for daytime (5 July 2015) and 4 am (6 July 2015) for all the densification scenarios. Notes: O = open rows; C = closed rows, 15/18 = 15/18 m building height, a/b/c = 1/4/8 underground car parks. Source: Sabrina Erlwein.

existing qualities are preserved. However, newly planted trees are unlikely to be fully grown trees, but rather small trees with limited crown volumes. Growing conditions for urban trees are often harsh due to limited growth volumes, compacted soils and reduced water availability (Moser, Rötzer, Pauleit, & Pretzsch, 2015). As the replanting of trees is time-consuming and often associated with high costs, the loss of old shade-giving trees cannot be easily compensated in the short or medium term. Where construction of underground car parks was limited to 50% and yards with fewer or smaller trees were selected for that purpose ('b'-scenarios) the PET increases through densification could be limited to +1.3°C for the daytime average (10 am to 4 pm).

5.1. Limitations of the Methodological Approach

The presented study focused on an extreme weather condition of severe summer heat and low wind speed to compare different densification impacts. This focus is due to the fact that climate change is likely to exacerbate already elevated urban heat. As a result, PET values for the chosen heat stress situation were very high; even in the shade of trees, thermal comfort levels remained on an extreme heat stress level. Since a heatwave with no rain preceded the modelling day, the soil humidity was decreased from 75% to 50% according to the available measurement data. Bande et al. (2019) found an overestimation of the mean radiant temperature values in ENVI-met due to the soil properties and report limits in the vertical moisture transfer with the top layer drying out too quickly. Thus, the exceptionally high PET values might have been caused by the limited availability of soil moisture. Nevertheless, the findings of this study are still considered valid, as the main focus of the study was set on comparing the relative differences between the investigated densification scenarios rather than on reporting the absolute PET values. All the simulation runs were performed under the same meteorological and identical full forcing conditions in the ENVI-met model.

The model outcomes are representative for similar building geometries, that are widespread in German cities. However, the impacts of building geometry alterations on the mean radiant temperature and subsequently PET are dependent on axis orientation and main wind directions (Chatzidimitriou & Axarli, 2017; Holst & Mayer, 2011). Due to the row building's NE–SW orientation, only a small part of the area benefitted from the enlarged shadow cast due to the increased building height during the hottest hours of the day. With an E–W orientation, additional shade due to higher building height might have made a more important contribution. For improved transferability of results, more axis orientations and main wind directions would need to be studied.

In light of climate change, we investigated thermal comfort situations for daytime and night-time for a hot summer situation. However, if planners seek to optimise thermal comfort throughout the year, potential trade-offs between different seasons should be considered. For instance, although detrimental in the summertime, wind-blocking by trees in winter might be beneficial especially in colder climates to reduce wind chill effects (Sjöman, Hirons, & Sjöman, 2016). However, from a climate change perspective, the situation of heat waves during hot summertime is of particular concern for climate-sensitive urban planning in Central European cities such as Munich.

5.2. Implications for Urban Planners

This study showed that trees play a pivotal role in heat stress mitigation and that preservation of existing trees is the most efficient and most affordable measure for climate change adaptation. In practice, the provision of new apartments leads to an increased need for parking spaces, resulting in tree removals. To balance housing demand and preservation of urban green space, the following recommendations can be given to urban planners.

First, particularly in the case of inner-city locations that are usually well connected to public transport, parking space ratios should be reduced by the employment of mobility concepts. Car-sharing and bike-sharing stations guarantee individual mobility, whereby strengthening of public transport is not only beneficial for the residents, but also for the entire neighbourhood (Stevenson et al., 2016).

Second, we recommend that architects and planners seek an early consideration of valuable mature vegetation in the built layout. If the construction of underground car parking is necessary, this should preferably be located in those areas with fewer trees. This is also important considering the fact that trees not only improve the local microclimate but also provide multiple ecosystem services such as stormwater retention, biodiversity and increased well-being (Hansen & Pauleit, 2014). In comparison to preservation, the replacement of trees is a time- and cost-consuming process.

Third, for the investigated free-standing multistorey housing type, densification through additional storeys is more beneficial in terms of climate adaptation than the addition of buildings. Although the addition of new buildings creates two to three times more new flats, this comes at the cost of lost unsealed open space and additional tree removals. The heat burden in closed building arrangements is significantly increased for areas with low wind speed, both for daytime and night-time. While shading by trees is an option to reduce daytime human heat stress (Lee et al., 2020; Rahman, Hartmann et al., 2020), tree canopies will exacerbate the nocturnal situation in those yards. Designs that consider nocturnal airflow will improve thermal comfort.

Finally, we recommend perceiving densification not only as a threat but also as a chance for upgrading urban green spaces and for introducing new green elements. To do so, we suggest the strategic planting of trees in thermal hotspots and taking care that good growing conditions are provided (see also Zölch et al., 2019). Green infrastructure elements can be combined with blue infrastructure elements such as rain gardens, to improve stormwater retention and water supply for the existing vegetation under dry conditions. Thus, meeting the increased housing demand can be achieved while green quality is increased.

6. Conclusions

This study investigated the impact of densification on urban green space availability and outdoor thermal comfort for an open midrise development site in Munich. Densification scenarios for a typical housing area of free-standing multistorey blocks in Munich were developed alongside planners and were thus considered to be realistic. We showed that the construction of parking space and the loss of existing trees have the greatest impact on PET outcomes. Replacing large trees is not only costly and time-consuming but is also ineffective in the short to medium term. Maintaining existing and mature vegetation reduces PET increase by 4°C compared to the base case (10 am to 4 pm). Thereby, the cooling effect during daytime outweighs the slight warming due to heat trapping at night. Wind blocking by buildings and trees reduces thermal comfort even in low wind conditions (<2 m/s). Thus, additional buildings should be carefully placed. Discussions with planners revealed that such quantitative information is urgently needed to consider the impacts of densification on human thermal comfort. Thus, this study contributed some important insights into urban planning. In light of climate change, mobility strategies that reduce the need for both above-ground and below-ground parking space are required for climate-sensitive densification of built areas. Future research should investigate thermal comfort during different seasons that have different requirements for light availability and shading. Other settlement types, benefits to stormwater management and the impacts or potentials of changed surfaces and materials, e.g., wood instead of concrete construction, require further investigation. Further studies should also analyse the perception of the quality of outdoor open spaces with regard to thermal comfort, but also the relationship between indoor and outdoor thermal comfort to arrive at a more integrative assessment of densification scenarios.

Acknowledgments

This study was realised within the project "Future green city" with financial support from the Federal Ministry of Education and Research (Germany). Special thanks are due to the urban planners at the city of Munich that provided information and insights into their working routines.

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 author (unedited).

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Urban Planning (ISSN: 2183–7635)
2021, Volume 6, Issue 1, Pages 20–31
DOI: 10.17645/up.v6i1.3515

Article

Integrating Green Infrastructure into Urban Planning: Developing Melbourne's Green Factor Tool

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Submitted: 28 July 2020 | Accepted: 29 September 2020 | Published: 26 January 2021

Abstract
As cities increase in size and density, the ecosystem services supplied by urban greenery and green infrastructure are increasingly vital for sustainable, liveable urban areas. However, retaining and maximising urban greenery in densifying cities is challenging. Governments have critical roles in addressing these challenges through policy development and implementation. While there has been significant attention on the quality and quantity of green space on public land, there is an increasing focus on policy mechanisms for integrating green infrastructure into the private realm, including green roofs, walls, facades, balconies and gardens. As part of City of Melbourne's efforts to increase greening across the municipality, its 2017 Green Our City Strategic Action Plan includes specific focus on the private realm, and development of regulatory processes for green infrastructure. This article reports on a participatory research project to develop a Green Factor Tool for application to building development proposals in Melbourne. We focus on the transdisciplinary collaborations that brought together contributions from researchers, practitioners, policymakers and designers. We discuss how local research on green space contributions to provision of ecosystem services shaped the design of the tool and provided the tool's rigorous evidence-base. Finally, we consider the roles of urban planning in retaining and maximising urban green spaces in densifying urban areas.

Keywords
biodiversity; climate change; ecosystem services; green; planning tools; regulation; sustainability; urban planning

Issue
This article is part of the issue "Urban Planning and Green Infrastructure" edited by Paul Osmond (University of New South Wales, Australia) and Sara Wilkinson (University of Technology Sydney, Australia).

1. Introduction

Urban green spaces contribute a wide range of functions, services and benefits towards creating more liveable and sustainable cities. Urban green spaces mitigate urban heat (Santamouris et al., 2018, pp. 6, 27), contribute to managing water runoff quantity and quality (Liu & Jensen, 2018), provide spaces for recreation, exercise and social activities (Kabisch, van den Bosch, & Lafortezza, 2017), as well as food growing and community gardens (Egerer et al., 2018), and habitat for biodiversity (Parris et al., 2018), with cities being home to proportionally high numbers of threatened (Ives et al., 2016) as well as more common species of fauna and flora (Kowarik, Fischer, & Kendal, 2020). Urban green spaces provide multiple functions (Hansen & Pauleit, 2014), even if they have been designed primarily for a single purpose. These multiple ecosystem functions have been described and categorised as 'ecosystem services' by the Millennium Ecosystem Assessment (2003).

Ecosystem services highlight the benefits provided to people, society and biodiversity by ecosystems. Since the Millennium Ecosystem Assessment landmark report in 2003, there has been substantial research focus highlighting the functions, benefits and values of ecosystem services, including in cities and towns (including for example, Connop et al., 2016; Cortinovis & Geneletti, 2018; Gómez-Baggethun et al., 2013; Haase et al., 2014; Hansen et al., 2015).

Local governments are increasingly focusing on greening the public realm through the planting of street trees and the creation and ongoing management of parks, gardens, town squares and other public spaces. However, greening on private land is also important, yet the mechanisms with which governments can influence this are often limited. To address this policy gap, several cities globally have developed green infrastructure assessment tools for application to building development proposals, including 'Green Factor Tools' in Seattle, Helsinki, Malmö and Singapore (Juhola, 2018; Kruuse, 2011; Ong, 2003; Slätmo, Nilsson, & Turunen, 2019). In Australia, the City of Melbourne (the central city municipality of greater metropolitan Melbourne) is working to increase greening across the municipality. The *Green Our City Strategic Action Plan* (CoM, 2017) focuses specifically on greening the private realm, and includes actions to develop and improve regulatory processes for integrating green infrastructure into new buildings and urban developments. The development of the Green Factor Tool is one of the actions explicitly listed in the strategy (CoM, 2017, p. 22).

This article presents the process of development of the *Green Factor Tool* for application to building development proposals in the City of Melbourne. We focus on the transdisciplinary collaborations that brought together contributions from researchers, practitioners, policymakers and designers. In the next section, we highlight the intersections between greening and land use planning, and introduce the policy background for development of the tool. The following section presents the stages of the tool's development, including the processes to construct the research evidence base that underpins the tool's structure and function. We show how the tool was customised for the Australian context, with considerable input from local research on how urban green space contributes to the provision of ecosystem services. The discussion focuses on the stages of policy development within City of Melbourne, and how the Green Factor Tool contributes to the city's suite of greening approaches. The City of Melbourne intends the tool to be applicable across the municipality, which includes both high density, multi-storey buildings, as well as areas of lower density, single or double-storey buildings. We conclude by reflecting on how the development of the tool highlights the potential for urban planning mechanisms to contribute to retaining and maximising urban green spaces in densifying urban areas.

2. Urban Greening and Land Use Planning

There is an increasing focus on the importance of 'urban greenery' (including green infrastructure and nature-based solutions) for sustainable and resilient cities, and the roles of policies in the provision of urban green spaces (Bush & Doyon, 2019; Cohen-Shacham, Walters, Janzen, & Maginnis, 2016; IPBES, 2019). Increasingly, urban land use policies are addressing green space provision as part of land use planning (Meerow, 2020; Scott et al., 2016). In addition, local and regional governments are developing urban forest, biodiversity and urban nature strategies (Aalbers, Kamphorst, & Langers, 2019; Bush, 2020; Pauleit et al., 2018). Recent initiatives, such as the CitiesWithNature platform, highlight the work of more than 170 cities across more than 50 countries that are actively working to integrate urban nature into city planning, development and management. In Melbourne, Australia, there has been considerable focus on greening policy and implementation. Melbourne is Australia's second largest city, with 32 local governments across the metropolitan area. The City of Melbourne (the central city's local government) has released a suite of greening strategies since the 2012 publication of its urban forest strategy (CoM, 2012). In 2019, Resilient Melbourne and The Nature Conservancy, in partnership with the 32 local governments, expanded the urban forestry approach to create a strategy for the whole metropolitan region (TNC & RM, 2019); and an increasing number of metropolitan Melbourne local governments are now developing urban forest strategies for their municipalities (Phelan, Hurley, & Bush, 2018).

While there has been a significant focus on the importance of retaining and maximizing greenery on public land, a substantial proportion of urban green space is located in the private realm, including in residential gardens (Marshall, Grose, & Williams, 2019). In the City of Melbourne, the local government owns and controls less than one third of the city's land area (CoM, 2017). While greening the public realm, in streets, parks, gardens and waterways, is essential for creating liveable, sustainable and resilient cities, a focus on private realm greening is also necessary to meet municipal greening and environmentally sustainable design targets, including increasing canopy cover; reducing water pollution associated with runoff; and increasing biodiversity, habitats, and ecosystem health, with the private realm identified as "playing a significant role in supporting nature in the city" (CoM, 2017, p. 27). Green infrastructure in private property is an important yet under-examined aspect of urban land use planning, with the majority of local government greening actions, as well as urban greening research focused on greening the public realm (Meerow, 2020). Furthermore, much of the attention on urban greening has focused on tree cover and urban forestry, with significantly less work on green roofs and vertical greening (Bathgate et al., 2020). There is a need to develop rigorous and effective policy mechanisms for retaining and maximising green space within the private realm. Policies, particularly requirements within land use planning provisions, can play a key role in targeting greening in new developments (Bush, 2020).

The City of Melbourne's suite of greening policies addresses a range of contexts and opportunities. While its 2012 Urban Forest Strategy made reference to 'green infrastructure,' including green roofs and vertical greening, the key focus was largely tree cover in streets and parks (CoM, 2012). Nonetheless, the strategy underpinned municipal efforts to develop skills, capacity and actions associated with greening the private realm, including development of the Growing Green Guide, a report providing an evidence base and technical guide for installation of green roofs, walls and facades (Victorian Department of Environment and Primary Industries, 2014). The City of Melbourne also undertook assessment of greening opportunities in the dense central city area (CoM, 2014), and offered grants to encourage implementation, through the Green Your Laneway pilot program (CoM, 2017). To specifically address greening the private realm, as well as to further encourage green roof and vertical greening implementation, the City of Melbourne released its *Green Our City Strategic Action Plan* in 2017 (CoM, 2017). In addition to 'leading by example,' developing and maintaining partnerships with Green Building Council of Australia and other groups, advocacy to other local governments and state government, the action plan explicitly includes a focus on development of regulatory mechanisms to require greening as part of new developments in the municipality.

As cities become increasingly dense, policy mechanisms for ensuring integration of greenery in new developments need to encompass the provision of green roofs, walls and facades, in addition to the greenery included in ground-level gardens. Therefore, policy mechanisms are required that can quantify both ground-level garden space and permeable undeveloped space, and the contribution of building-integrated greenery. Several cities have developed assessment tools for application during the planning and design phases for new buildings. Berlin was one of the first cities to introduce an assessment tool, with the Biotope Area Factor introduced in 1994 (Climate-ADAPT, 2016). These tools provide mechanisms for quantifying the amount of greenery integrated into new developments, frequently in the form of a numerical value for the ratio between the built areas and green areas of the property or lot (Juhola, 2018).

These existing tools have provided the inspiration for City of Melbourne's development of its Green Factor Tool (CoM, 2017; GHD, 2013). In developing the Melbourne Green Factor Tool, City of Melbourne aimed to create a rigorous, evidence-based tool customised for local conditions, that would contribute towards meeting a range of its policy objectives, as well as environmentally sustainable design targets (CoM, 2017, pp. 6, 27). Further, the development of the tool for Melbourne aimed to strengthen or improve on key features of existing tools from other cities. While there has been only limited research on green factor tools globally, with most of the research focused on simply identifying or describing tools rather than critically analysing their coverage or performance, Juhola (2018) review of Helsinki's tool, highlighted that key improvements could be made in relation to monitoring of the tool's application, and in setting ambitious targets that developers must meet. City of Melbourne also undertook several comparative assessments of the strengths and weaknesses of a range of these tools (CoM, 2017; GHD, 2013). These reviews contributed to the initial planning for the development of Melbourne's Green Factor Tool, but also highlighted the necessity for further targeted research as part of the tool development process (CoM, 2017). As the ultimate objective is to pursue changes to the planning scheme to make the use of the tool mandatory in the development process, the tool needed to be based on credible and defendable research, with a specific focus on local research, to ensure it is resilient to scrutiny.

There is currently little published research of how green rating tools are developed and applied (Ade & Rehm, 2020; Juhola, 2018; Kruuse, 2011; Slätmo et al., 2019), or their comparative strengths, weaknesses or opportunities for improvement or extension; this case study seeks to contribute to this body of knowledge by presenting the process for research, development and piloting of the City of Melbourne's Green Factor Tool.

3. Green Factor Tool Development

The development of the Green Factor Tool was undertaken between April and June 2019, followed by testing and modification to the end of 2019, and the tool's launch, for voluntary usage, in May 2020. The development process involved a comprehensive, transdisciplinary collaboration between policymakers, sustainable building and landscape practitioners, software designers and researchers. The consultancy team appointed by City of Melbourne to develop the tool was led by HIP V. HYPE Sustainability, with tool and website design by Little Sketches, and research input from University of Melbourne researchers. This article focuses primarily on the research input, which contributed both to the design of the tool (including identifying greenery forms, functions, scoring) as well as to building a comprehensive and rigorous evidence base to support decision making, policy adoption and roll out of the tool. The stages in the tool's development are summarized in Table 1.

3.1. Stage 1: Identifying Green Infrastructure Forms and Functions

The first stage for tool development involved defining the different forms and functions of greenery that the tool would include. The forms largely correspond with typologies commonly utilised by landscape architects, design-

Table 1. Green Factor Tool development stages.

Stage	Detail
1. April 2019	Identifying green infrastructure forms and functions
2. April 2019	Prioritising functions
3. April–May 2019	Researching the evidence base
4. May 2019	Rating the vegetation forms for relative delivery of functions
5. May–June 2019	Peer review of scoring and evidence matrix: practitioners and researchers
6. June–December 2019	Finalisation of Tool design, piloting

ers and urban ecologists (Bull, 2014): large tree (10m or more); medium tree (6m–10m); small tree (3m–6m) and climbers (on structures); large shrub (2m or more); small shrub (up to 2m); ground cover and understorey; lawn or turf (mown). The functions provided by greenery, that are relevant for the urban context and deliverable at building scale were identified, based on reviewing both urban ecosystem services (Gómez-Baggethun et al., 2013) and City of Melbourne's policy priorities for urban greening (CoM, 2017). The eight functions identified were: urban temperature regulation (cooling effect); habitat for biodiversity; run off mitigation; air purification; food supply; recreation; place values and social cohesion; and aesthetic benefits. Of these eight functions, three are 'regulating ecosystem services' (providing biophysical functions), and three are 'cultural ecosystem services.' As such, the tool recognises the significant contribution that ecosystems, vegetation and urban nature can make to both environmental and social outcomes, consistent with the large body of social-ecological research (Lafortezza, Chen, van den Bosch, & Randrup, 2018; McPhearson, Haase, Kabisch, & Gren, 2016). The tool aims to balance comprehensiveness with ease of use, so not all of the possible urban ecosystem services were included; instead the tool focused on those ecosystem services that could feasibly deliver benefits at the lot scale. Ecosystem services that require larger scale greenery to provide the function were not included. For example, while carbon sequestration is an important ecosystem service, due to the relatively low quantities of sequestered carbon associated with lot scale greening in urban areas (Chen et al., 2020), it was not included in the tool.

3.2. Stage 2: Prioritising Functions

The second stage focused on prioritising the functions (ecosystem services). A workshop was held with City of Melbourne staff from a range of policy domains (Council departments) to prioritise the functions based on local strategic priorities, as well as with reference to local context and conditions. The workshop participants were drawn from strategic and statutory planning, urban design, open space planning, urban landscapes management, landscape architecture and urban ecology. As such, the process for prioritising functions involved input from a range of disciplines, including, but not limited to environmental or landscape planning domains. This ensured that a wide range of policy priorities and objectives were considered and assessed. Workshop participants together discussed and negotiated the relative priority of the different functions, based on policy priorities, as well as their experience of how urban greenery, vegetation and landscaping elements are incorporated into development plans (Table 2).

3.3. Stage 3: Researching the Evidence Base

The third stage involved building the evidence base, which demonstrates the delivery of each of the identified ecosystem services, to underpin the Green Factor Tool's rigor and credibility. Policy makers favour locally

Table 2. Stage 2: Prioritising functions.

Function priority (highest first)	Ecosystem service
1. Urban temperature regulation (cooling)	Regulating
2. Habitat for biodiversity	Supporting
3. Runoff mitigation	Regulating
4. Recreation	Cultural
5. Air purification	Regulating
6. Place values and social cohesion	Cultural
7. Aesthetic benefits	Cultural
8. Food Supply	Provisioning

based and generated research as the most relevant for informing and justifying decision-making (Bush, 2020). Therefore, the research review process was based on the following hierarchy of relevance: Melbourne, southeast Australia, southern Australia, Australia, temperate urban contexts globally. Local literature reviews (Davern, Farrar, Kendal, & Giles-Corti, 2017; Kendal, Lee, Ramalho, Bowen, & Bush, 2016) were utilized to identify relevant research, as well as identifying key local green infrastructure researchers. In addition, the Scopus research database was used to identify the most recent relevant research findings. Database searches were based on (key word: function) and limited to (source country: Australia). The key words used in the searches were the function terms (Table 2). Citations of key references were also reviewed to identify other more recent relevant research. The research aimed to identify the most local findings that demonstrated delivery of the function by the different forms of vegetation. As such, the research process sought to create a context specific, rather than comprehensive evidence base. A matrix of forms and functions was created to summarise the research and record sources.

The resulting research evidence-base matrix included a summary of how vegetation delivered each of the ecosystem functions and the key characteristics associated with maximising the function's delivery (Table 3). The evidence base matrix also included details differentiating the relative delivery of each function for each vegetation form. For example, tree canopy contributes both shade and evapo-transpiration for urban temperature regulation, whereas understorey vegetation provides only evapo-transpiration. The research identified 73 key sources of research on these functions, including journal articles, books, and reports.

3.4. Stage 4: Rating the Vegetation Forms for Relative Delivery of Functions

Following the development of the research evidence base, the fourth stage involved rating each of the vegetation form's delivery for each of the functions. The urban greening forms (large tree, medium tree, etc.) were rated between 0 (no contribution), 0.5 (minimal contribution), 1 (minor contribution), 1.5 (minor-moderate contribution), 2 (moderate contribution), 2.5 (moderate-major contribution) to 3 (major contribution) in terms of their relative capacity to deliver each of the functions. The determination of the relative capacity of the different forms was based on research findings identified in stage 3, and related to whether the delivery of the function was proportional to size (or height) of vegetation, or other factors such as visual amenity or food production (Table 4). Higher ratings were allocated for use of locally native (indigenous) plant species. The rating of forms, combined with the weighting of functions, generates a Green Factor Score that enables the assessment of the different types of green infrastructure provision and design (ground level landscaping, green roofs, walls and facades) for new developments. The scoring underpins a focus on achieving City of Melbourne's policy objectives that span sustainable building performance, urban ecology and biodiversity, social health, and wellbeing.

3.5. Stage 5: Peer Review of Scoring and Evidence Matrix: Practitioners and Researchers

Using the evidence-base matrix that details the forms and associated scores for each of the functions and the supporting research, four separate workshops were held during May 2019 to peer review the research outputs. Workshop one was with one landscape architecture researcher; workshop two was with three urban ecology researchers; workshop three was with more than 10 green infrastructure and urban ecology researchers; and workshop four was with four Council staff from the landscape and planning teams. Discussion focused on reviewing the local research on delivery of functions by different forms, and on the proposed scoring system.

The peer review process was an important element of the overall research process and tool development, particularly in being able to provide multi-disciplinary feedback and comments on the evidence-base matrix. The tool development aimed to construct a tool that is as comprehensive as possible, yet also focuses on the key functions and benefits that vegetation could deliver at lot scale. Importantly, the peer review process led to the removal of air purification from the tool, leaving seven key functions (Table 5). While there was recognition of the documented role of vegetation in mitigating different forms of air pollution (Escobedo & Nowak, 2009; Jayasooriya, Ng, Muthukumaran, & Perera, 2017; Tiwari et al., 2019), discussions with local researchers highlighted that Australian cities are not exposed to the same magnitude of urban air quality challenges, compared with many other cities around the world. This is largely due to existing Australian regulations and standards for vehicle emissions, which are a main source of urban air pollution (Chang et al., 2019). Further, our peer reviewers suggested that the most effective and efficient way to continue to address urban air quality is through emissions standards rather than suggesting (or implying through inclusion of air quality in the Green Factor Tool) that vegetation should be expected to mitigate this type of pollution.

With the finalisation of function weightings, combined with the ratings of vegetation forms in delivery of functions, a Green Factor Score can be generated. The Score represents the proportion of a site covered by greenery, and weighted for provision of prioritised functions.

3.6. Finalisation of Tool Design and Piloting

Following the finalisation of the research evidence-base, and scoring of functions and forms, the web-based tool

Table 3. Summary of research evidence-base matrix.

Function	Vegetation's role in ecosystem function	Mechanism for delivery	Key determinants of relative delivery	Selected key references
1. Urban temperature regulation (cooling)	Vegetation can reduce urban heat and contribute to human thermal comfort	Shade Evapo-transpiration	Leaf area Canopy volume Degree of irrigation	Duncan et al. (2019); Livesley, McPherson, and Calfapietra (2016)
2. Habitat for biodiversity	Vegetation provides habitat for biodiversity (and is itself biodiversity)	Shelter Food 'Benevolence' (conditions to enable completion of life cycle)	Species: indigenous Structural complexity No pesticides or pollutants; minimise noise, disturbance, night time light	Maclagan, Coates, and Ritchie (2018); Parris et al. (2018); Shaw, Miller, and Wescott (2017); Threlfall et al. (2016, 2017)
3. Runoff mitigation	Vegetation and soil can reduce the quantity of stormwater runoff	Soil water retention: permeability/percolation Canopy interception	Substrate volume Substrate permeability Leaf area Canopy volume	Livesley et al. (2016); Ossola, Hahs, and Livesley (2015)
4. Recreation	Vegetation/green space can provide opportunities and location for recreation	Doing (active) and being (passive) in accessible green space: physical activity (walking, gardening), play	Accessibility	Davern et al. (2017); McCormick (2017)
5. Air purification	Vegetation can contribute to improving air quality	Dry deposition (surface area) Atmospheric turbulence (surface roughness)	Leaf level attributes (hairiness, waxiness) Leaf area Canopy volume	Escobedo and Nowak (2009); Tiwari et al. (2019)
6. Place values and social cohesion	Vegetation and green space can contribute to the 'sense of place' and provide the location for social connections	Emotional and spiritual connections; cultural landscapes; sense of place; shared interests, participation	Community scale/social cohesion Visibility Accessibility	Davern et al. (2017); Dickinson and Hobbs (2017)
7. Aesthetic benefits	Vegetation and green space can contribute to the aesthetics/beauty of place	Sensory connections: psychological benefits, stress reduction, recovery; sense of wellbeing	Visibility	Davern et al. (2017); Lin, Egerer, and Ossola (2018)
8. Food Supply	Vegetation can produce food, fibre, etc	Food production, connection with broader food system	Productive food species	Lin et al. (2018); Zainuddin and Mercer (2014)

was developed. Unlike many of the Green Factor Tools used in other cities, the City of Melbourne version utilises a web interface. This allows 'open access' (without relying on users needing licence access to Excel spreadsheets) as well as opportunities for a more user-friendly interface design and usability, and the ability for the tool owner (in this case City of Melbourne) to update the tool without concerns for version control.

The web-based tool (CoM, 2020) calculates a Green Factor Score based on the relative volume and weighting of green elements, in comparison to the overall area of the site. The first step requires tool users to enter details on the project site, including address, total site land area, land use and building typology (small-scale residential, multi-unit residential, retail/shop, commercial/office, industrial/warehousing, or public build-

Table 4. Delivery of functions rated for different vegetation forms.

	Large tree 10m+	Medium tree 6m–10m	Small tree 3m–6m & climbers (on structure)	Large shrub 2m+	Small shrub up to 2m	Ground cover/ under-storey	Lawn/turf
1. Temperature regulation	3	3	2.5	2	2	2* 1**	2* 1**
2. Habitat provision	3	3	2.5	2	2	1.5	0.5
3. Runoff (quantity)	3	3	2.5	2	2	2	2
4. Recreation	3	3	2.5	1	1	1	2
5. Air purification	3	3	3	3	3	1	0
6. Place and social cohesion	3	3	3	2	2	2	1
7. Aesthetic	3	3	3	2	2	2	2
8. Food production	2***	2***	2***	2***	2***	3***	0

Notes: * = irrigated, ** = unirrigated, *** = productive food only.

ing) and a short description of the proposed development. The second and main step is for tool users to enter details of the green infrastructure elements (type and area) of their proposed development. For the purposes of the tool, 'green infrastructure' includes both vegetation and soil elements. The tool requires that users specify whether the green infrastructure is in ground (existing retained), inground (new), green wall, green façade, planters (on structure), or green roof. Based on the input data, the tool generates a Green Factor Score that takes into account the relative volume and efficacy of green elements, in comparison to the overall area of the site.

Following completion of the tool's design and construction, it entered a pilot stage (July 2019–February 2020) for testing and calibration. The pilot stage had the objectives of ensuring that the tool is robust and capable of application by different users (the tool is designed to be used by landscape architects, architects, Ecologically Sustainable Development consultants and other built environment professionals) and to the range of expected green infrastructure assessments. The pilot stage also included a process for determining a target Green Factor Score that design proposals will need to meet. To determine this, a range of different designs for residential, commercial and industrial developments were inputted to the tool to assess the spread of Green Factor Scores for different amounts and forms of greenery in different development contexts. This process helped to ensure that the settings were sufficiently sensitive to differentiate between designs.

Targets for Green Factor Scores were set at 0.55 for residential and commercial developments (corresponding to a horizontal green cover of 40% site coverage), and 0.25 for industrial developments (CoM, 2020). The Green Factor Score is lower for industrial building typologies because the piloting process found that opportunities to integrate greenery are more limited in industrial contexts due to requirements for creating clear access for both delivery and emergency vehicles. Following the piloting process, the Tool was made publicly available for voluntary use by developers (CoM, 2020), with an online launch held on 26 May 2020. The City of Melbourne's policy development approach is to monitor the tool's use by designers and developers during this voluntary phase, with the intention to pursue changes to the Melbourne Planning Scheme, that would integrate an assessment metric for greening targets (CoM, 2017). There is a need for future research to assess and analyse the impacts

Table 5. Urban Ecosystem Services in order of priority included in the Green Factor Tool.

Function	Weighting	Ecosystem service
1. Urban temperature regulation (cooling)	25%	Regulating
2. Habitat for biodiversity	20%	Supporting
3. Runoff mitigation	20%	Regulating
4. Food supply	10%	Provisioning
5. Recreation	10%	Cultural
6. Place values and social cohesion	10%	Cultural
7. Aesthetic benefits	5%	Cultural

of the tool's use in achievement of City of Melbourne's greening and environmental sustainability targets and objectives. Further research could also include comparative analysis of Melbourne's Green Factor Tool and those of other cities including Berlin, Helsinki, Malmö, Seattle and Singapore.

4. Discussion

The development of Melbourne's Green Factor Tool was underpinned by a staged process that involved input from both researchers and practitioners at multiple points, to complement the review and assembly of the research evidence base. The transdisciplinary process was supported by the assembly of an effective consultancy team with complementary skills, clear communication channels, and clear allocation of specific tasks with clear timelines. The development of the Green Factor Tool demonstrates how local governments can support transdisciplinarity by requiring academic input to consultancies and by valuing academic research as an essential element of the evidence-base. As such, this article contributes to understandings of effective models for exchange and collaboration between researchers and planners in urban planning (Hurley, Lamker, & Taylor, 2016).

The peer review process strengthened the rigour of the research evidence base, as demonstrated by the review and removal of air quality from the list of vegetation functions included in the Tool. However, the lack of inclusion of air quality as one of the Tool's functions was questioned during the pilot phase, and particularly during the summer of 2020 when many of Australia's cities were blanketed in smoke from catastrophic bushfires (Head, 2020). As urban Australians struggled to breath, with some cities experiencing thick smoke for up to one month, there was a renewed focus on the health impacts of smoke and other sources of air pollution (Vardoulakis, Marks, & Abramson, 2020; Walter, Schneider-Futschik, Knibbs, & Irving, 2020). However, urban vegetation would have had minimal effects in mitigating the sheer magnitude of smoke generated by the bushfires, which was observed by NASA satellites as it circled the globe. Nonetheless, the tool development process, which involved a thorough research process, followed by the peer review process, provided policy makers with a credible and reliable evidence base, as well as a degree of confidence, when called upon to explain and justify the inclusion or exclusion of functions and the construction of the scoring and targets for the tool.

Likewise, City of Melbourne's suite of greening policies has also been important in building awareness, interest, support and capacity for increasing greening implementation. The comprehensive suite of greening policies now spans policies for the public and private realms; addresses urban forest and tree canopy, green roofs, walls and facades, urban ecology and biodiversity; encompasses community engagement, skills and industry development; and planting on local government managed land as well as funding provision for greening on land owned and managed by others (Table 6). Likewise, the Green Factor Tool itself is intended to shift through pilot and voluntary phases before its inclusion in the planning scheme requiring mandatory application. As such, this diversity of approaches can be seen to have contributed to a multi-pronged approach to increasing greening uptake across the municipality that addresses strategic, operational and engagement dimensions of policy development, and potentially underpins and increases policy success (Bush, 2020).

5. Conclusions

The development of City of Melbourne's Green Factor Tool has shown how research can inform and support policy development, and how transdisciplinary collaboration can lead to more rigorous and locally relevant outcomes. The tool's development was underpinned by peer reviewed research, both in its reliance on research to build the supporting evidence base, and in the peer

Table 6. Development of City of Melbourne's greening policy suite (selected policies and programs).

Year	Policy	Greening context	Key areas of focus
2011	Citizen Forester program	Public green space	Community engagement
2012	Urban Forest Strategy	Tree canopy, public realm	Strategic planning
2014	Growing Green Guide	Green roofs, walls and facades	Technical guide
2015	Canopy quarterly discussion forum	Green roofs, walls and facades	Industry skills development
2016	Green your laneway pilot	Green roofs, walls and facades	Funding
2017	Nature in the city strategy	Urban ecology, biodiversity	Strategic planning
2017	Green Our City Strategic Action Plan	Green roofs, walls and facades	Strategic planning
2018	Urban Forest Fund	Urban greening	Funding
2019–2021	Green Factor Tool	Greening private realm	Voluntary-mandatory planning provision

Source: Adapted from CoM (2017).

review process of the tool's development. This research input supported the development of a rigorous and credible tool, and strengthened policy makers' confidence in the final tool output.

The resulting Green Factor Tool is available for use through a web-based interface (CoM, 2020). It has been designed for use by landscape architects, architects, environmentally sustainable design consultants and other built environment professionals as part of the development approval process. The development of the tool has sought to balance comprehensiveness with ease of use to promote its uptake. The tool's design brings together research on the functions (ecosystem services) provided by green infrastructure at the lot scale, with the policy priorities and objectives of the City of Melbourne, to weight and score the green infrastructure contributions.

The development of the Green Factor Tool demonstrates local government leadership in supporting the increased provision of greenery in new development. The tool and its development process can be applied by other cities, to contribute towards objectives of increased greenery within urban buildings and precincts. Further research will be necessary to assess and analyse the tool's contribution to increasing greening and environmental sustainability outcomes as the tool is integrated into urban development planning and approval processes. As more cities adopt these regulatory tools, further research to provide comparative analysis of the tools will be important to inform and encourage best-practice approaches.

Acknowledgments

The authors thank all those involved in the workshops that informed the development of the Green Factor Tool. The authors thank the Academic Editors and reviewers for their valuable feedback and comments on this article.

Conflict of Interests

All authors were involved in the development of the Green Factor Tool. Judy Bush and Gavin Ashley were part of the consultancy team appointed by City of Melbourne to develop the Green Factor Tool. Ben Foster and Gail Hall were both employed by City of Melbourne during the development of the Green Factor Tool. Ben Foster is currently employed by City of Melbourne.

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Urban Planning (ISSN: 2183–7635)
2021, Volume 6, Issue 1, Pages 32–48
DOI: 10.17645/up.v6i1.3499

Article

A Soft Systems Methodology for Business Creation: The Lost World at Tyseley, Birmingham

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Submitted: 24 July 2020 | Accepted: 30 November 2020 | Published: 26 January 2021

Abstract
Much has been written about the benefits of green infrastructure, but securing the resources necessary for its development and long-term maintenance is often difficult. This article's premise is that, in general, people and organisations will take action to provide those resources when they can see value accruing to them; therefore narratives of value generation and capture (our definition of business models) are required to motivate and support that action. This article explores the application of soft systems methodology to the wicked problem of business model development in the context of a social enterprise, using a case study based on a piece of green infrastructure in the city of Birmingham, UK, called The Lost World. The research involved a workshop with several of The Lost World's key stakeholders and aimed at identifying: The Lost World's scope as a business; its potential value streams; and how they might be realised in a social enterprise. Analysis of the findings shows that while stakeholders can identify opportunities for their organisations, bringing those opportunities to fruition is difficult. The research demonstrates a compelling need for social entrepreneurs to act as catalysts and long-term enablers of the formulation and maintenance of businesses and business models—vital missing actors in the ambition to transform cityscapes.

Keywords
business model; green infrastructure; social enterprise; value

Issue
This article is part of the issue "Urban Planning and Green Infrastructure" edited by Paul Osmond (University of New South Wales, Australia) and Sara Wilkinson (University of Technology Sydney, Australia).

1. Introduction

Much has been written about the benefits of green infrastructure, but securing the resources necessary for its development and long-term maintenance is often difficult. This article argues that, in general, people and organisations will take action to provide those resources when they can see value accruing to them and, therefore, narratives of value generation and capture, referred to herein as business models, are required to motivate and support that action. Typical business models with their focus on profit generation are unlikely to be suitable. Instead, social enterprise business models offer a potential way forward. They have specific social, environmental, and economic objectives extending well beyond concerns typically associated with corporate social responsibility (Seanor, Bull, & Ridley-Duff, 2007), which may be better at supporting green infrastructure by providing a hybrid approach that combines delivery of social purpose and maintenance of financial stability (Emam, 2016). However, whether profit-driven or social-enterprise, business model creation is a 'wicked problem' that "[does] not have a single outcome and [is] associated with a high degree of uncertainty," and "[is] dispersed amongst a host of actors [that requires] co-creation of knowledge to bridge social, environmental and economic tensions" (Henriques, 2018, p. 463). This can only be initiated by conversations that coalesce into a collective narrative (Pollastri et al., 2018). This article explores whether soft systems methodology (SSM) has a part to play in helping to address this complexity in the context of creating social enterprise business models for green infrastructure, and considers the potential role for social entrepreneurs. It starts with a review of the literature on the application of SSM to business models at the city scale, before narrowing the focus to green infrastructure and social enterprises. The research into novel approaches to business model creation is then described, including a workshop held with stakeholders to develop a social enterprise business model for a piece of green infrastructure in Birmingham, UK, called The Lost World. Finally, there is a discussion of the role for social entrepreneurs and conclusions are drawn.

2. The Application of SSM to Social Enterprise Business Models in the Context of Green Infrastructure: A Literature Review

2.1. SSM at the City and Sub-City Scale

Generating value in the development of local businesses requires a systematic view of the different approaches. In the literature review, we explored systematic thinking approaches and found 8,160 records in the Social Sciences Citation Index in the last five years. This yielded 698 papers in educational research, 641 in environmental sciences, 622 in management, and 612 in environmental studies. Due to the interest in green businesses specifically, relevant papers in environmental sciences were explored. These provided evidence of a shift to the system thinking approach, used by organisations to evaluate the challenges from different perspectives; for example, exploring the livelihood of an area and acceptance of sustainable projects (González, Sandoval, Acosta, & Hena, 2016; Sánchez-García, Ramírez-Gutiérrez, Núñez-Ríos, Cardoso-Castro, & Rojas, 2019). Often, this means that a single-view solution to address a challenge is no longer adequate; rather it requires a system-of-systems approach, and this usually applies to inherently-complex urban projects for which planning should consider solutions using mapping analysis (Bedinger, Beevers, Walker, Visser-Quinn, & McClymont, 2020). This approach can support future design and foresee sustainable solutions, a practise which will educate future generations and advance sustainability science (Gray et al., 2019; Onat, Kucukvar, Halog, & Cloutier, 2017). It is necessary to support the right conditions for mutual understanding between all those involved in commercial and sustainability projects (Ahlström, Williams, & Vildåsen, 2020). A systems thinking approach helps in addressing issues of sustainability, for example when tackling climate mitigation and planetary wellbeing, and delivering sustainable solutions—a practise which requires, and supports willingness to sustain, political power in the future (Berry, Waite, Dear, Capon, & Murray, 2018; Király, Köves, & Balázs, 2017). All of this suggests that systematic thinking is taking the lead in the development of sustainable future solutions (Gu, Deal, & Larsen, 2018; Williams, Kennedy, Philipp, & Whiteman, 2017). These solutions should aim not at the methodological practises, but rather at the efficacy of their application; for example, not in the ways of how sustainable the products or services are, but whether the application of the solution or organisation will be sustainable in the future (Moldavska & Welo, 2016; Patel & Mehta, 2016).

Having established above that creating business models to generate and capture value is a 'wicked problem' due to the lack of a single outcome and a high degree of uncertainty, then an approach that is founded on 'advancing by learning' is necessary. SSM, often attributed to Checkland (Checkland & Haynes, 1994; Checkland & Scholes, 1999), offers a framework for the solution of such problems, which can be conceptualised at a high level as an iterative learning process as shown in Figure 1 (Bouch, Rogers, Powell, & Horsfall, 2018). The process starts with a description of the real-world situation of concern: For example, creation of a sustainable green infrastructure business. Once the business is defined, stakeholders, stakeholder requirements, and value generation opportunities can be identified and synthesised into potential, purposeful activities for change, which can then be assessed against the existing system to see whether they are systemically desirable and culturally feasible. Implementing change completes the first iteration by creating a new real-world situation ready for further refinement.

A search of SSM literature published in the last five years found 201 records in the Social Sciences Citation Index, of which 100 concerned management, 38 operations research, 16 industrial engineering, and 15 interdisciplinary social science. SSM is mostly a knowledge-learning task between the participants, a process of exploration and observation (Caceres & Wiesenborn, 2019). The literature suggests that approaching a 'soft' issue requires an explicit rather than implicit understanding of the issue itself, which acknowledges the context, and those involved—this requires a systems methodology (Hanafizadeh & Ghamkhari, 2018). Equally, communication barriers are highlighted as an important consideration, interpretation may vary between those who conduct the research, and inter-organisational cultures can differ markedly, and so the systems analysis should be tested to identify these and similar problems of the method (Caceres & Wiesenborn, 2019; Nguyen,

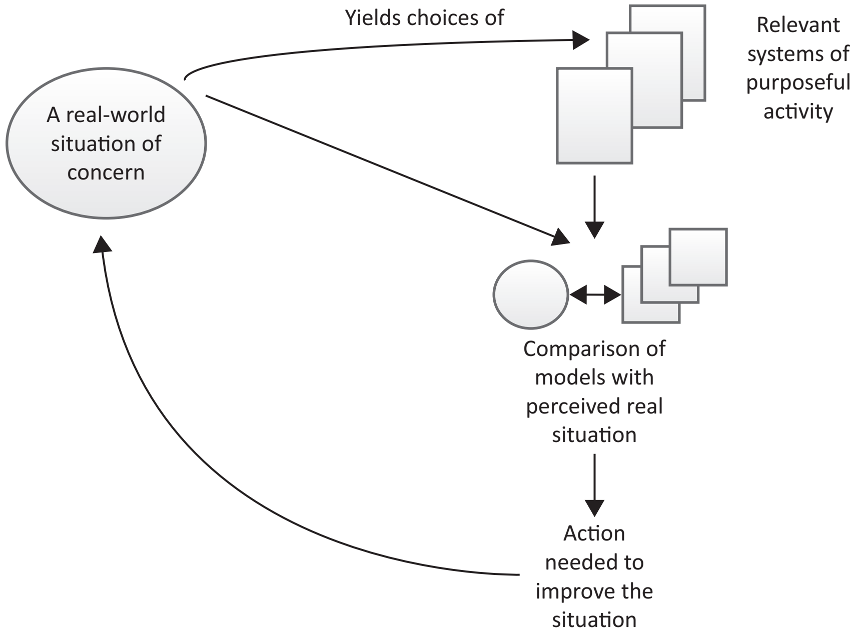

Figure 1. A simplified depiction of SSM. Source: Adapted from Checkland and Scholes (1999).

Scognamillo, & Comer, 2019). Likewise, social norms, political views, and leadership style can affect SSM—this is a matter to explore among stakeholders (Kish, Bunch, & Xu, 2016).

The literature review showed that significant research has been carried out over the past 15 years elaborating on the high-level SSM stages described above. A wide range of these papers has recently been brought together as the UKCRIC Infrastructure and Cities Methodology, where UKCRIC is the United Kingdom Collaboratorium for Research on Infrastructure and Cities (UKCRIC, 2021). The steps in the methodology, which was originally developed to address city-scale problems, are set out in Table 1. Entries 1 to 4 in Table 1 correspond to that part of Figure 1 identifying the real-world situation. Entry 5 covers the SSM activity of identifying relevant systems of purposeful activity. Entries 6 to 14 relate to the SSM's comparison of models with the perceived real situation; and, entries 15 to 17 are all about the action need in SSM to improve the real-world situation.

2.2. Social Enterprise

A search on social enterprise in Web of Science found around 400 papers of which 150 were on management, 120 on business, 64 on environmental studies, and 59 on environmental sciences. In order to help understand how social enterprise can be created, the literature review concentrated on the more highly cited (over 20 citations) management papers to identify key issues in the management of the social enterprise. For example, Tracey and Philips (2015) concluded that a lack of responsibility across all levels of social enterprise could negatively impact on the social value of the organisation. The aim is for value generation to be a sustainable practice and for it to influence multiple sectors over time to support the local economy as whole—this requires local stakeholders' involvement, i.e., from those who probably have knowledge of resources and also the wider political agenda (Altinay, Sigala, & Waligo, 2016; Dey & Teasdale, 2016). In this way, decision-making responsibility can be distributed to ensure sustainability in business development (Akemu, Whiteman, & Kennedy, 2016). To overcome the uncertainty inherent in social enterprises, in which social aspects are the key components, communication between stakeholders is a vital consideration (Bontis, Ciambotti, Palazzi, & Sgro, 2018). While a democratic approach between the stakeholders is essential, communication at a senior level to support diversity and innovation and ensure the sustainability of the business as a social enterprise is also required (Crucke & Knockaert, 2016). In socially responsible enterprises, the action model should be easy to understand and it should be possible to explore interdependencies and limitations in a transparent manner (Sánchez, Bolívar, & Hernández, 2017; Zahra, Gedajlovic, Neubaum, & Shulman, 2009). This will allow the aims and objectives of the organisation or business to include identification of opportunities via a bottom-up approach (Choudrie & Zamani, 2016). While traditional organisations aim for a business approach, the role of the social-stakeholders can be complementary, such as by helping to explain how to be sustainable in the future (Lee, Herold, & Yu, 2016). The challenge of financial planning will remain a concern, but the 'why and how' can positively contribute to the long-term social welfare (Wry & York, 2015). An overall shift of the business model towards social enterprise requires an understanding and exploration of limitations, and building stakeholders' trust in this different approach (Dey & Teasdale, 2016; Upward & Jones, 2016).

Table 1. Summary of the UKCRIC infrastructure and urban systems methodology.

	Lessons from Cities Research	Evidence Base References
1	Address a specific infrastructure and urban system problem, assemble an appropriately broad, multi-disciplinary, multi-sectoral group of potentially interested parties, including users of the outcomes	Rogers et al. (2014) Wilson, Tewdwr-Jones, and Comber (2019)
2	Understand deeply the aspirations of the city and its people	Rogers (2018) Rogers and Hunt (2019)
3	Diagnose fully the problems	Leach, Mulhall, Rogers, and Bryson (2019)
4	Establish the baseline performance of the city in terms of its sustainability, resilience, and liveability	Bouch and Rogers (2017) Leach et al. (2016) Leach, Lee, Hunt, and Rogers (2017)
5	Apply ingenuity to create solutions to the problem	Caparros-Midwood, Barr, and Dawson (2017) Powell, Glendinning, and Dawson (2018) Rogers (2018)
6	Assess the impact of the interventions on the city's infrastructure and urban systems	Leach et al. (2017) Leach, Rogers, Ortegon, and Tyler (2019)
7	Conduct a futures analysis to explore whether the interventions are vulnerable to future contextual change (i.e., are resilient)	Lombardi et al. (2012) Rogers, Lombardi, Leach, and Cooper (2012)
8	Use numerical and scenario modelling to predict near and far future need for infrastructure and urban system services: Do solutions meet these needs?	Hall, Tran, Hickford, and Nicholls (2016) Ives, Simpson, and Hall (2018) Rogers et al. (2012) Rogers (2018)
9	Make the case for change	Leach et al. (2017) Leach, Rogers, et al. (2019)
10	Develop a suite of alternative 'business models'	Bouch and Rogers (2017) Bryson et al. (2018) Rogers (2018)
11	Understand all of the dimensions of governance (formal and informal) relevant to the intervention and the context	Honeybone, Collins, Barnes, and Cosgrave (2018) Leach, Rogers, et al. (2019) Rogers (2018)
12	Trial infrastructure and urban systems interventions in UKCRIC's Laboratories	
13	Trial infrastructure and urban systems interventions in UKCRIC's Urban Observatories	
14	Trial infrastructure and urban systems interventions in UKCRIC's Modelling & Simulation Facilities	
15	Influence policy	Honeybone et al. (2018) Rogers et al. (2014)
16	Influence practice	Leach, Rogers, et al. (2019) Rogers (2018)
17	Inform and engage the public	

2.3. Green Infrastructure

Sustainability is deeply rooted in the UK Government's strategy '*A Green Future: Our 25 Year Plan to Improve the Environment*' (Defra, 2018), which aims to bring the environment to future generations in a better state than it is today, through the benefits of natural as well as social and economic capital. Natural capital needs to be supported by green infrastructure placed in the urban context (Arup, 2014), making a vital contribution to more sustainable living and providing wider benefits to urban living while mitigating some of its adverse consequences, features that require more conscious inclusion in the smart cities discourse (Cavada, Hunt, & Rogers, 2016; Mora & Deakin, 2019). Yet green infrastructure is a system that underpins a wider agenda in sustainability; an urban ecosystem that is healthy and resilient contributes to biodiversity conservation and benefits human populations through the maintenance and enhancement of ecosystem services in a systematic approach to enhance living in urban contexts (Naumann, McKenna, Kaphengst, Pieterse, & Rayment, 2011). Urban green infrastructure supports people in a number of ways: for example, regulating urban microclimates, providing recreational facilities, bolstering flood resilience measures, supporting local food supplies, improving water and air quality, and fostering urban biodiversity (Arup, 2014; Breuste, Artmann, Li, & Xie, 2014). However, this green infrastructure system would be difficult to fund and maintain, because funders often find it difficult to capture a share of the benefits arising. Economic value, as perceived by investors, is a matter of financial return and maximisation of land value is often a primary driver of urban development (Arup, 2014). Along with the problem of value capture lie the difficulty of securing political will, governance issues and competing priorities, while austerity measures can only make funding for sustainability and natural environment benefits more challenging (Centre for Cities, 2019; House of Commons, 2017).

Similarly, natural capital accounting techniques, developed to create stronger business cases in the urban realm, have been met with limited success. Natural capital accounting can quantify "natural capital stocks and service flows to determine the nature and scale of [the benefits generated], and how they vary over time, and whether management and use of natural capital is sustainable" (Faccioli, McVittie, Glenk, & Blackstock, 2018, p. iv). This is linked to the idea of the developing green economy and the emergence of markets for ecosystem services (Sullivan, 2014). However, while natural capital accounting can help to measure the potential benefits of green infrastructure, it does not make them any easier to realise, as illustrated by Hoelzinger and Grayson (2019). Using a natural capital accounting approach, they calculated a net present benefit of nearly £11 billion from the green spaces managed by Birmingham City Council over a period of 25 years, but with many of the value 'streams' identified (for example, mental health benefits, air quality, biodiversity) difficult to capture. An alternative approach is to explore whether narratives of value generation and capture (business models) can be created to help support green infrastructure. This will allow stakeholders to create value and capture a share in the form of a social enterprise, with a sustainable approach (of social, environmental, and economic objectives) seeking to combine the delivery of social purpose and maintenance of financial stability (Emam, 2016; Seanor et al., 2007; Zott & Amit, 2010).

3. Aim and Objective of Study

The aim of the research is to explore whether SSM can contribute to the development of business models to support the provision of urban green infrastructure. The objective is to demonstrate the role that SSM can play through a case study based on a piece of green infrastructure in Birmingham, UK, called The Lost World.

4. The Lost World

The Lost World extends to approximately 18.5 hectares in southeast of Birmingham, straddling the boundary between Tyseley & Hay Mills and Balsall Heath council wards. It is an urban area that still tries to protect its distinctive character and develop local economic activity and involvement. The case study involved a workshop with the principal stakeholders. Figure 2 shows The Lost World in relation to Birmingham city centre, while Figure 3 shows that The Lost World is an oasis of 'green' in comparison with the surrounding industrial areas.

The aim of the workshop was to involve interested stakeholders from the local community, who could articulate their knowledge of and future aspirations for the area. The academic team was keen to understand and explore with them their interest in the area, identify value opportunities for their organisations and understand challenges in realising this value, and together generate value for the future of The Lost World.

5. Shaping the Future of Tyseley & Hay Mills: Outcomes from the Lost World Workshop

The Tyseley area is considered one of the most deprived wards in the City of Birmingham and is within the 10% most deprived wards in the UK (Birmingham City Council, 2019). The local authority councillor for Tyseley & Hay Mills, the Hay Mills Foundation Trust and Webster & Horsfall Holdings Limited, a long-established wire manufacturing company and owner of Tyseley Energy Park (TEP), have been driving the economic regeneration in the area based on low carbon, alternative energy technologies; however, importantly, they also have a desire to improve the environmental quality of Tyseley. The Hay Mills Foundation Trust is a charity established in 2015 by Webster & Horsfall Holdings Limited. Its principal activity is creating a historical record of the Webster and Horsfall operations, but it also has a remit to engage with the local community to promote connections between the company and the local community (TEP, 2020). Table 2 lists the stakeholders who were invited to, and took part in, the workshop and their respective visions. It shows that most of the participants' visions/missions relate strongly to an environmentally sustainable future of the Tyseley & Hay Mills area.

Twenty-four stakeholders representing the above organisations took part in a half-day workshop on 24th

Figure 2. The Lost World in relation to Birmingham city centre.

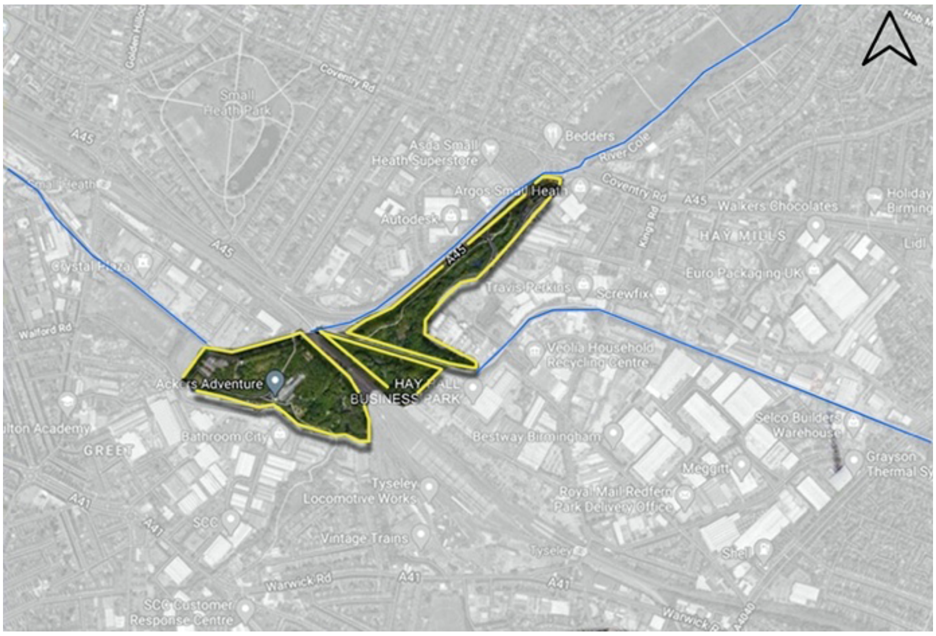

Figure 3. The Lost World showing the Grand Union Canal (running ~E-W) and the River Cole (running ~SE-NW).

October 2019 to explore what The Lost World might be. The workshop was facilitated by Hay Mills Trust, along with the research team (three from the University of Birmingham and one from Birmingham City University). The stakeholders were arranged into four mixed groups (labelled red, green, yellow and blue; these colours are used in the tables below) and asked to explore the following questions. Session 1: What areas of interest can you see in The Lost World? Session 2: What sort of value-generating opportunities can you see in The Lost World? Session 3: What steps need to be taken to help The Lost World generate value for your organisation, and what things could get in the way?

5.1. Session 1: Areas of Interest and Boundaries

In addressing this question, the stakeholders were asked to think about where The Lost World's borders might best be placed in order to support the visions/missions of the organisations they were representing. Within those borders, they identified factors they felt might make an important contribution to their organisation's existing operations. Areas of interest are shown in Figure 4. A central area combining parts of the canal and greenery (yellow strip) generated the most interest as the focal point of future activity, both for itself and considering the outward views to the surroundings. Other desirable features

Table 2. The Lost World stakeholders and their visions/missions.

Stakeholder (reference)	Stakeholder Visions/Missions
West Midlands Police (2020)	Prevent crime and protect the public
Ackers Adventure (2020)	Provision of leisure outdoor activities
Birmingham Open Spaces Forum (2020)	Having an interest in the City's parks and open spaces
ND Landscape Architects Ltd (2020)	Innovative landscape architecture, garden design and arboriculture practice
St Cyprian's Church (Church of England, 2020)	An open all-religious community
Birmingham Energy Institute (2020)	Academic Centre of Excellence on energy
TEP (2020)	Drive industrial growth alongside green technologies
Environment Agency (2020)	Create better places for people and wildlife
Canal and River Trust (2020)	Sustain and revitalise British waterways
Inspired Steps (2020)	Changing communities towards sustainable living
Vintage Trains (2020)	Preserve and demonstrate steam locomotives; museum attraction based in Tyseley
Birmingham Education Partnership (2020)	Secure a deeply good academic, social and civic education for every child and young person living in Birmingham
Hay Mills Foundation Trust (2020)	Engage with the local community to promote the history and heritage (particularly of Webster & Horsfall) on the Hay Mills site
Birmingham City Council (2017)	An enterprising, innovative, and green city
Local councillor	Serve the local community
Local residents	Interested in the area

Figure 4. Stakeholder area mapping combined central blue-green space (yellow), an innovation hub (blue), and educational facilities (green).

identified included an innovation hub (blue star) to bring industrial, business, and local knowledge into an accessible forum, with a reach into the adjoining extended industrial area of TEP, and enhanced cohesion amongst educational facilities in the area, which were considered to extend sporadically across the north and northwest parts of the wider area (green circles). Notably, the discussion extended beyond the given site boundaries, indicating the area's potential to influence the surrounding areas.

Four main areas of stakeholder interest emerged during the discussions in each of the four groups: community building, the various forms of value provided by the area's greenspace, the opportunities offered by TEP to the local community, and educational opportunities arising from the local area. Table 3 provides brief summaries of the discussions transcribed by the researchers following the workshop.

5.2. Session 2: Value Generating Opportunities

In Session 2, stakeholders were presented with an introduction and explanation of the structure and development of the Generic Value Map shown in Figure 5 (Bouch

Table 3. Goals and stakeholder areas of interest in The Lost World.

Goals	Stakeholder Areas of Interest
Community building	• A community centre in the area centred on St Cyprian's church • Reaching out from St Cyprian's church to connect with local schools and faiths • The local communities around the existing industries and the opportunity for industry to participate in strengthening connections • Tyseley & Hay Mills and Small Heath council wards • Working collaboratively to create an area of safety • The catchment area from which shoppers are drawn to Tyseley's store • Generally, interest in the local community
Valuing greenspace	• The opportunity to link and develop (a) green corridor(s) • The Akers site is available to promote health and wellbeing (H&WB) • A blue corridor and green corridor from Heritage Trains to Akers, providing visiting opportunities and improved access • A green corridor linking the Vintage Trains site to Heybarnes, improving access and increasing visitor numbers • The canal itself and the land bordering it to a distance of one kilometre on either side provides valuable leisure and educational opportunities • The River Cole Valley: improving access for safety, visiting, and cultural purposes • Flood risk areas along the River Cole valley • River Cole connected catchments, upstream and downstream • Opportunities for public access to the River Cole • The green corridors along the River Cole and Grand Union Canal
TEP and the local community	• Energy research & innovation hub centred on TEP • Sustainability centred on Tyseley Environmental Enterprise District • Low carbon innovation centred on Tyseley Environmental Enterprise District • Green transport centred on Tyseley Environmental Enterprise District • The area around the existing factory and its potential for economic growth • Heritage aspects of the area around the existing industries and the opportunity for industry to maintain and build on them • The linking of visitor attractions (canal, river, greenspaces) to create an integrated attraction • Strengthening links between Birmingham's city green vision and The Lost World • Strengthening links between industry and academia to support volunteer groups and secure the long-term future
Educational value	• Opportunity to educate about and involve children in maintaining greenspaces • Opportunity to involve parents in children's education • Build career aspirations around sustainability and the environment • Support schools by providing learning activities in the area (on both urban and green environments) • Opportunity to strengthen curricula in the local area • Tyseley & Hay Mills and Small Heath council wards to offer educational space

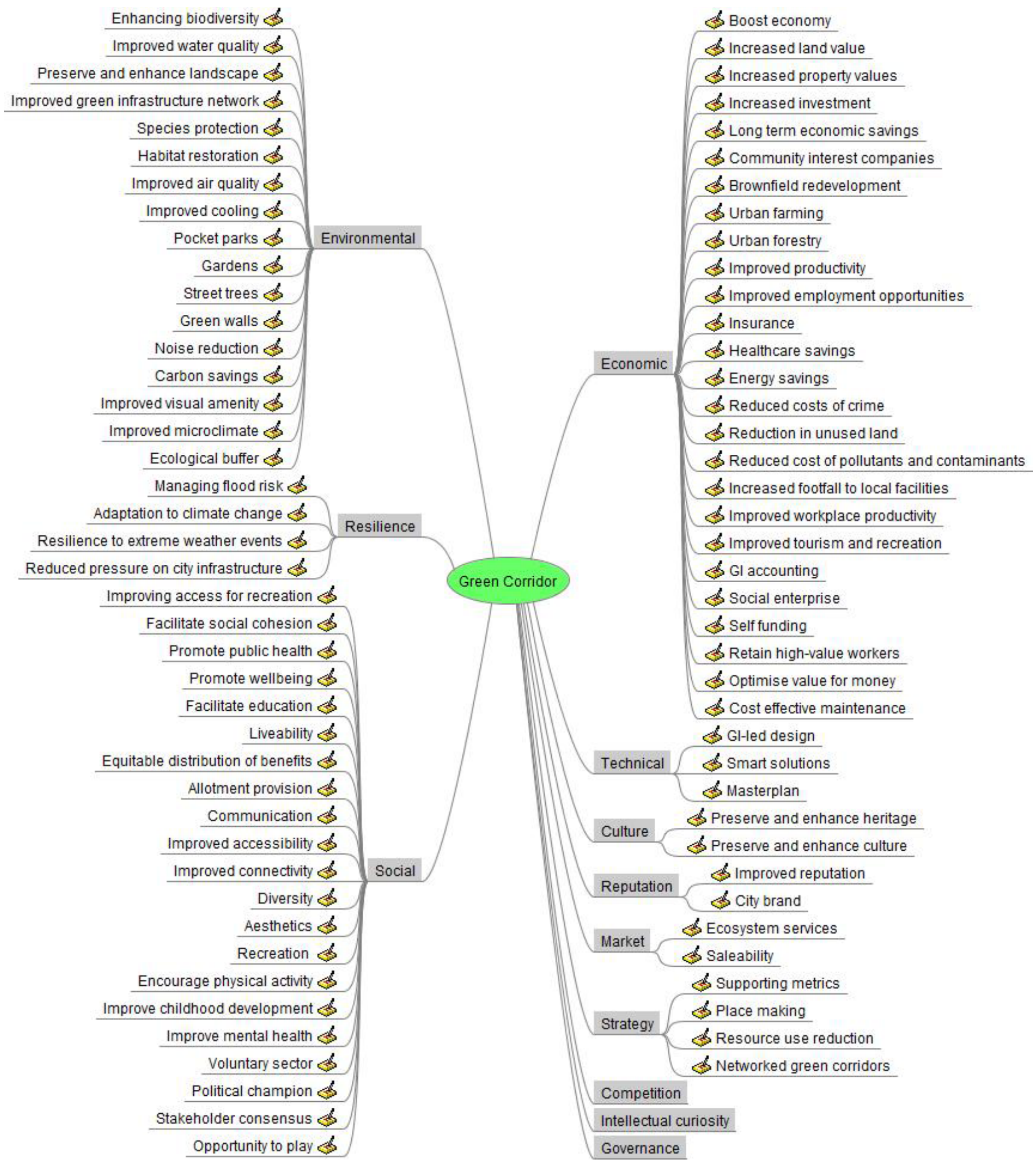

Figure 5. Generic value map identifying value generating opportunities for businesses.

et al., 2018). Through discussion, stakeholders identified 97 potential opportunities that were categorised into 25 areas by the research team. In general, all groups suggested opportunities (mostly around 20 each, although the yellow group suggested 37), providing a good indication of all voices being heard. Further analysis identified five high priority value-generating ideas (Table 4) and five lower priority value-generating ideas (Table 5). Initially the discussion centred around topics identified in Session 1 (e.g., a community hub and a research & innovation hub), but now the discussions turned to a more focused approach on value generation, such as the benefits of social cohesion, improved H&WB, and visiting opportunities. In addition, opportunities were identified to inform established organisational structures and strategies, such as collaboration with the local Council (on Birmingham's Biophilic City status), resilience (insurance sector) and land value (commercial land development). The approach was that business models should evaluate and demonstrate the multiple benefits across economic, social, environmental and governance domains by doing things differently (e.g., designing and implementing initiatives to realise visions and ambitions) and show to the stakeholders how they could act in support their delivery (Cavada, Hunt, & Rogers, 2017; Rogers, 2018).

5.3. Session 3: Limitations and Opportunities for The Lost World

In this session, each group discussed how the value-generating opportunities identified in Session 2 might be brought together to create a business model for The Lost World while delivering value to their own organisations. Both the green and blue groups focussed on a hub in collaboration with TEP. For them, green infrastructure was already considered to be included in TEP's vision—this now should work as a catalyst and extend beyond

Table 4. High priority value-generating opportunities identified by the four stakeholder groups (denoted by different colours).

Goals	Stakeholder Identified Value Generating Opportunities	Group
Social cohesion	Community integration	Green
	Community ownership	Green
	Consultation for community empowerment	Green
	Creation of community spirit	Red
	Improve the attractiveness of the area	Red
	Pride in area	Yellow
	Getting people out of their area and silo	Yellow
	Culture	Yellow
	Resident ownership—collective responsibility	Yellow
Improved health & wellbeing	Amenity value for employers and tenants	Blue
	Social awareness and education bringing physical and mental health benefits	Blue
	Healthy lifestyles: encourage people to be outdoors more	Green
	Actions to enhance wellbeing	Green
	Improving the canal and towpath as a 'wellbeing' environment	Red
	Calm environment	Yellow
	Actions to enhance H&WB	Yellow
Community hub	Community interest and support enabling growth	Blue
	Engage the community to help keep the church open	Blue
	Connectivity	Green
	Provision of a public house as a community-meeting place	Red
	Attracting different audiences—all organisations community hub and space	Yellow
	Community hub and space	Yellow
	Invest in religious places	Yellow
Visitors	Bring people into area	Blue
	Garden walks [leading to] increased visitor numbers	Blue
	Increased use of the canal by people living in a 2-kilometre-wide corridor, centred on the canal.	Red
	Local tourism from city centre	Yellow
	Generate income	Yellow
	Business due to increased footfall	Yellow
Research and innovation hub	Increase research impact	Blue
	Research and modelling of value	Green
	Technology development	Yellow
	Green technology	Yellow
	New service providers	Yellow
	Finding opportunities	Yellow

the point of focus to provide benefits to other areas, for example in reducing crime levels in the area. The yellow group spoke about a hub of a different kind: they focused on a community-based hub, one that could have the church at its centre, providing a spiritual connection to H&WB. It was also suggested to provide connections and business opportunities for the hub, such as for Ackers' leisure activities and for visitors. Leisure also provided the focus for the red group, which suggested that the River Cole should form part of the wellbeing strategy for the area. This strategy would aim to improve access and maintenance of the blue and green infrastructure and complement the Environment Agency's infrastructure improvement plan for the area.

Table 5. Lower priority value-generating opportunities identified by the four stakeholder groups.

Goals	Stakeholder Identified Value Generating Opportunities	Group
Volunteering	Community to feel ownership and responsibility	
Strategy	Commonwealth Games would benefit from positive environmental improvements. Align with City Council strategies.	
Land value	Potential (commercial?) land value	
Resilience	Improving local environmental resilience	
Flood risk	Reducing flood risk	

6. Limitations and Opportunities for The Lost World

The majority of stakeholders identified funding as being the biggest challenge. In the past, when funding was in place, it was often for a short duration and did not support a diverse range of business activities. This led to a tendency to focus on short-term initiatives as well as providing a constraint on aspirations for the long-term, sustainable future of The Lost World. Lack of specific business funding can also be a barrier. However, there are now opportunities to test initiatives for their alignment with wide-ranging visions and aspirations (Rogers & Hunt, 2019) and for their long-term as well as short-term efficacy, notably using alternative future scenarios to test for resilience (Rogers, 2018). Alongside funding, communication was considered a major constraint. That there is no current space to bring stakeholders together, both in spatial and opportunity terms, was deemed to be the most important barrier to communication. However, this concern also applied to communication links aimed at the educational opportunities around the area, even though TEP and the University of Birmingham would appear to provide excellent opportunities.

It was emphasised that the green areas lacked a joined-up infrastructure, prohibiting access and benefit-delivery for many of the stakeholders. Such an infrastructure mechanism, via interconnected green corridors linking also to the river and canal, could be readily foreseen, but is yet to materialise. Interestingly, this did not form one of the priority goals in Tables 4 and 5, and yet it would manifestly support many of the goals. This is a classic example of an engineered intervention that would deliver multiple benefits, and indeed was used as the primary example by Rogers and Hunt (2019) of how to deliver Birmingham's and Bristol's city visions. In a similar way, volunteering failed to emerge as a high priority, though it would act as a catalyst for delivering on the high-priority goals. Its value as a business-generated opportunity might superficially appear low, yet, as found in the literature, volunteering can affect positively social enterprises. Therefore, in the case of The Lost World it could prove a positive and important addition; and, if this were allied to the maintenance of local green infrastructure ('nurturing one's local place') the business models become more attractive, delivering a wide range of value including: cost savings, greater social cohesion, H&WB benefits from engagement with nature, educational opportunities, improved biodiversity, improved local aesthetics and a better sense of place, encouragement to active travel (further benefitting H&WB), and so on.

Crime, safety, and anti-social behaviour were also identified as a challenge for the area and social cohesion. Stakeholders highlighted the challenge of managing the area due to the extent of unused and dark areas, suggesting these provide space for anti-social activity. The design of schemes to create green and blue corridors would therefore need to take these factors into account and engineer them out. It was pointed out that improvements to the area could also bring benefits for the educational facilities in the surrounding areas, and that these should be consciously 'designed in' at the planning stage. More generally, as a holistic entity The Lost World along with TEP should reach out to local schools and develop joint activities, potentially using the facilities on site as learning hubs. Volunteering could likewise play a part in this.

It was also interesting to note that local government policy and strategy were considered to be of lower priority, though it was suggested that this was due to the lack of local government funding reaching The Lost World. Additionally, access from and connection to central Birmingham was also considered to present limitations: this area could easily be overlooked because of its detachedness. These comments were evidenced by the lack of direct connection to the Government's New Industrial Strategy, with Birmingham City Council's plans for the 2022 Commonwealth Games, and with The Canal and River Trust's strategy. Addressing this lack of integration into such planning should be a priority for local governance and councillors.

Drawing these observations together, it was suggested that an overarching green and wellbeing agenda to improve living in the area is also currently missing from local policy. This should form a central argument in the push to deliver aspirational change since it would provide the foundation for multiple forms of value generation, as advocated by Rogers and Hunt (2019). Although it was agreed by most in the room that a wellbeing agenda is needed in The Lost World, the stakeholders found it difficult to see how to bring this about, especially at the stage where a collective agreement on what should be done is still underway. Nevertheless, the workshop sessions uncovered many strands that might feature.

7. Discussion

This research aimed to answer the question of how SSM can play a part in the creation of social enterprise business models for green infrastructure and take advantage of local 'heritage' assets, illustrated with a case study based on The Lost World. The research reviewed existing literature around a systems approach using SSM applied to social enterprises and found that there was a strong focus on addressing management and environmental issues. Our research investigated how SSM could be used to create new business models for The Lost World and hence to bring about change. Traditionally, those businesses that currently depend on the availability of external funding adopt a fiscal 'return on investment' focus. They tend to concentrate on land development (hence increased land value), yet this can lead to adverse consequences (i.e., disbenefits, lost opportunities, or negative value) for the future of the urban area and local communities.

It was for this reason that a social enterprise approach was explored, which requires a participatory, democratic, and transparent process in which the 'whys' and 'hows' are explored with stakeholders to develop solutions and decision-making (Crucke & Knockaert, 2016; Lee et al., 2016; Sánchez-García et al., 2019). To support this a mapping exercise was carried out with stakeholders to understand the efficacy of the application and provide an alternative and documented methodological approach into the SSM (Moldavska & Welo, 2016; Patel & Mehta, 2016), taking specific cognisance of the multiple challenges presented by the local context (Hanafizadeh & Ghamkhari, 2018).

This initial work proved effective in providing the foundations necessary for collective discussion and in attracting all of the key stakeholders in our case study site to engage in the research via a series of workshop sessions. We therefore recommend this as an approach that can be used no matter what the context or goal, noting that the process itself led to benefits in terms of local stakeholder cohesion. Building on this, we trialled the use of SSM to develop collective, evidence-based business models for the sustainable future of The Lost World. The workshop sessions revealed shared values amongst the local stakeholders that could serve as the core proposition for (a) business(es) and identified a series of opportunities for value creation, including social, environmental, educational, H&WB, and economic (e.g., attracting visitors) benefits. Integrating these benefits and setting them against the costs, and any other adverse consequences, of making the changes necessary to realise the vision for The Lost World would constitute the initial 'business models'—-the framework that balances positive outcomes against negative outcomes (one of which is that a financial investment would need to be made) associated with the changes.

Each of the proposed changes (e.g., creation of a community hub, creation of interconnected green corridors linking to the river and canal) would be associated with its own set of benefits, costs and other consequences, of course, and each could then undergo iteration. For example, in the case of creation of interconnected green corridors there would be both a capital cost and a maintenance cost, and yet if local volunteers were to engage in maintenance then the latter cost would be reduced to that associated with training and equipping a group of local volunteers and the business case would be stronger. Such iteration of designs and business models (to enhance benefits and/or reduce costs) lies at the heart of the UKCRIC methodologies detailed in Table 1 (Rogers, 2018).

Alongside the opportunities, the workshop revealed some local challenges that might not have been (fully) appreciated (e.g., crime, safety, pockets of unused and 'dark' areas that could accommodate anti-social behaviour). Identifying and surfacing such opportunities and local challenges is useful to inform the SSM value map further and refine designs and business models. It is only when this holistic iteration is complete should the 'case for change' be articulated (Rogers, 2018), founded on a comprehensive, transparent and accessible evidence base and supported by equally comprehensive, transparent and accessible business models, hence helping to remove uncertainty and de-risk decision-making. Work on analysing and aligning all forms of governance to ensure the business models work can then be undertaken. The formal forms of governance (e.g., legislation, regulations, codes & standards, taxation, and incentives) and informal forms of governance (e.g., individual and societal attitudes and behaviours, social norms, practice norms, etc.) both need to be considered to determine what might limit the success of the changes being proposed.

The research has resulted in the following recommendations:

- Application of SSM should be an iterative process. The first stage, reported herein, required considerable prior research and analysis, yet provided rich datasets and information, and a development of understanding and trust amongst stakeholders, that would enable firm proposals to be created with confidence. Once these have been created, and ensuring that the designs are co-created with the relevant stakeholders, a second workshop is suggested to provide more specifically-targeted discussions on the proposals and explore further the issues that emerged in the first workshop, such as how funding can generate social entrepreneurship for the detailed proposals.
- More specifically, the above research provides the foundation for the creation of new initiatives (or 'businesses') to support the development of The Lost World. These should now be explored with stakeholders, both as traditional urban development proposals (though with a stronger, and far

wider, articulation of the multiple benefits that they have the potential to generate) and social enterprises. The business models and case for change will reflect the multiple benefits identified and support the discussions.
- There is a need to provide examples of previous business models that have been created and tested at the urban scale (i.e., one that is large enough to embrace the influence of green infrastructure and heritage assets) to generate evidence of the successes and failures, with a particular emphasis on whether, and how well, they have supported the various local stakeholders' vision/missions.
- There is a need to develop and provide examples of the application of SSM. The synthesis of the current limitations and opportunities identified in the first Lost World workshop, and reported above, is a good example of the detail required.
- The workshop was facilitated by researchers who have a deep appreciation of the literature, methodologies and their implementation in practice, and who were able to carry out the prior work. Accepting that such support will not usually be available, there is a compelling need for social-enterprise entrepreneurs to act as catalysts and long-term enablers of the formulation and maintenance of such businesses and business models—these are the vital missing actors in the ambition to transform urban areas to benefit the people who live and work there. Recognising this need, and providing training to create such a capability, is therefore important.

8. Conclusions

This research aimed to explore how social enterprise can generate value and whether application of the SSM would help define the multiple forms of value that would provide the foundation for new, broader business models to support change. The research focussed on the opportunities offered by largely overlooked and undervalued greenspace and heritage assets in a major city. A large cohort of relevant stakeholders were convened in a workshop in which the SSM approach was adopted and this was found to provide a useful framework for the development of business models for improvements in the Tyseley area of Birmingham, UK. Stakeholders explored common interests and visions and identified opportunities, and limitations, for value generation associated with development of The Lost World, an area of green and blue space within a heavily developed, mixed-use area of Birmingham, yet one with a rich industrial heritage, lying approximately four miles from the city centre. Opportunities for value generation included social, environmental, educational, and H&WB, as well as economic, benefits, while communication, funding, safety, and governance issues were raised as some of the challenges that would need to be addressed.

The research demonstrated that the crucial first stage of the process of creating synergistic change to a deprived area of a city could be achieved via a single workshop primed with considerable prior work. Indeed, the level of participation showed that local communities and businesses would like to be part of a local enterprise approach to develop business models that would enhance and sustain their local area. It also demonstrated the need for stakeholder involvement from conception and throughout every stage of the business development if the greatest value (fullest set of benefits, and delivery of the broadest set of stakeholder visions) is to be achieved. Building on the foundations of this first stage, specific proposals can now be developed with confidence to advance the development of The Lost World via what might be termed sustainable green infrastructure and community businesses.

The Lost World is representative of overlooked or forgotten areas of land that seem to have no sustainable future—areas that remain unused, do not attract funding, potentially facilitate anti-social behaviour, and become a barrier to social cohesion. In the case of The Lost World there is an impetus and energy from local actors to make positive changes, and this allowed the research team to build on its long history of research into sustainable, resilient, and liveable cities to apply its thinking, experience, and methodologies to explore how this change could be made to greatest effect. However, recognising that this type of support will not usually be available, the research has demonstrated a compelling need for social-enterprise entrepreneurs to act as catalysts and long-term enablers of such beneficial change. They would be tasked with carrying out the prior work on the place in question and setting in motion the sequences of activities and methodologies described above, leading to the formulation and sustainment of businesses and business models needed to support the change. We conclude, therefore, that social-enterprise entrepreneurs are the vital missing actors in the ambition to transform urban areas to benefit the people who live and work there.

Acknowledgments

The authors gratefully acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Sciences Research Council (ESRC) under grant numbers EP/J017698 (Liveable Cities: Transforming the Engineering of Cities to Deliver Societal and Planetary Wellbeing), EP/K012398 (iBUILD), EP/P002021 (Urban Living Birmingham), EP/R017727 (UK Collaboratorium for Research on Infrastructure and Cities Coordination Node) and MR/T045353 (REPLENISH: REimagining PLaces and ENgineered Infrastructure Systems for Health). The research programme was led by Professor Rogers at the University of Birmingham with the university's support; the additional support from Lancaster

University, Birmingham City University and the Hay Mills Foundation Trust is also gratefully acknowledged.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2021, Volume 6, Issue 1, Pages 49–62
DOI: 10.17645/up.v6i1.3491

Article

The Eco-Techno Spectrum: Exploring Knowledge Systems' Challenges in Green Infrastructure Management

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Submitted: 20 July 2020 | Accepted: 15 October 2020 | Published: 26 January 2021

Abstract
Infrastructure crises are not only technical problems for engineers to solve—they also present social, ecological, financial, and political challenges. Addressing infrastructure problems thus requires a robust planning process that includes examination of the social and ecological systems supporting infrastructure, alongside technical systems. An integrative Social, Ecological, and Technological Systems (SETS) analysis of infrastructure solutions can complement the planning process by revealing potential trade-offs that are often overlooked in standard procedures. We explore the interconnected SETS of the infrastructure problem in the US through comparative case studies of green infrastructure (GI) development in Portland and Baltimore. Currently a popular infrastructure solution to a wide variety of urban ills, GI is the use and mimicry of ecological components (e.g., plants) to perform municipal services (e.g., stormwater management). We develop the ecological-technological spectrum—or 'eco-techno spectrum'—as a framing tool to bridge all three SETS dimensions. The eco-techno spectrum becomes a platform to explore the institutional knowledge system dynamics of GI development where social dimensions are organized across ecological and technological aspects of GI, exposing how governance differs across specific forms of ecological and technological hybridity. In this study, we highlight the knowledge system challenges of urban planning institutions as a key consideration in the realization of innovative infrastructure crisis 'fixes.' Disconnected definition and measurement of GI emerge as two distinct challenges across the knowledge systems examined. By revealing and discussing these challenges, we can begin to recognize—and better plan for—gaps in municipal planning knowledge systems, promoting decisions that address the roots of infrastructure crises rather than treating only their symptoms.

Keywords
Baltimore; ecosystem services; infrastructure crises; integrated planning; interdisciplinarity; knowledge systems analysis; Portland; science and technology studies; social-ecological-technological systems; water management

Issue
This article is part of the issue "Urban Planning and Green Infrastructure" edited by Paul Osmond (University of New South Wales, Australia) and Sara Wilkinson (University of Technology Sydney, Australia).

1. Introduction

The United States (US) has an infrastructure problem. While innovative technological fixes are often the focus of rhetoric around infrastructure solutions, it is important to recognize that each physical break-down—a pothole, leaky pipe, or cracked foundation—is a material manifestation of social-political (as well as technical) cause and effect (Grabowski et al., 2017). Therefore, to 'fix' the infrastructure problem in the US, we cannot attend only to physical or technical aspects. We must look to integrated frameworks of infrastructure–such as the social-ecological-technological systems (SETS) framework—to find solutions to chronic breakdowns in service delivery (Markolf et al., 2018).

A SETS framing can integrate municipal institutions and urban planning processes as key facets of the infrastructure problem. A prominent institutional barrier is path dependency: institutions are often unable to easily adjust to new conditions or adopt new solutions that do not fit into fixed institutional approaches and structures (Munoz-Erickson, 2014). For example, stormwater management infrastructure is sized using standardized 'design storms,' which are calibrated to historic storm frequency and intensity. In light of climate change influences on the amount and intensity of precipitation, historic storm data is increasingly insufficient to appropriately size infrastructure (Adams & Howard, 1986; Watt & Marsalek, 2013). However, debate regarding the legitimacy of climate science, the obdurate nature of legally binding permitting agreements, and uncertainty regarding which climate projection to use has stalled efforts to update design storms throughout the US (McPhillips, Matsler, Rosenzweig, & Kim, 2020).

The system of techniques in which municipal institutions gather, vet, use, and circulate different types of information to make decisions can be conceptualized as knowledge systems (Miller & Munoz-Erickson, 2018). 'Knowledge systems analysis' consists of examining the taken-for-granted procedures and practices institutions use to approach solution development and uncovering the embedded values and visions of how the world works within them (Munoz-Erickson, 2014). Analysis of knowledge systems can help answer underlying interdisciplinary questions related to the US infrastructure problem (Miller, Chester, & Munoz-Erickson, 2018), including *how can we design infrastructure decision-making to integrate social, ecological, and technological solutions to better achieve desired outcomes on-the-ground*?

Visions of how the world works impact material reality by constraining the set of solutions we individually or collectively pursue moving forward; this problem-framing necessarily favors some communities and disadvantages others (Bowker & Star, 1999). Even within seemingly apolitical technical management, social negotiations between worldviews are taking place, embedding certain values into material infrastructures that constrain or ease the actions of our daily lives (Lampland & Star, 2009). Many of these negotiations are quite mundane, occurring in bureaucratic spaces where experts frame problems and design potential solutions. But the seemingly straight-forward technical nature of these decisions often obscures the fact that they represent political actions (Edwards et al., 2013). Urban planners have long recognized the power inherent in problem-framing, exemplified by an evolution of communicative and participatory planning techniques through time (Carmon & Fainstein, 2013; Forester, 1982; Healey, 1997). We present knowledge systems and SETS as important tools in the planning toolbox to continue this evolution.

Here, green infrastructure (GI) is a site of inquiry used to explore the knowledge systems influencing infrastructure decision-making in the US today. GI employs directly, or mimics, ecological processes in combination with engineered systems to deliver municipal services, making it an excellent site of explicit intersection between SETS domains. The ecological-technological spectrum of GI—or eco-techno spectrum—is developed as a heuristic to systematically structure an examination of GI knowledge system challenges across the three SETS domains. This spectrum highlights the different degrees to which ecological entities (e.g., plants, soils, microbes) are incorporated as infrastructural components in GI facilities. This inclusion presents a major social challenge to GI implementation in that it brings ecological knowledge into traditionally engineering-dominated decision-making where it does not easily integrate with established procedures for defining or measuring facilities (Finewood, 2016; Matsler, 2019). The eco-techno spectrum adds needed granularity to research on this system by organizing interdisciplinary connections across specific GI facility types.

In current urban resilience discourse, GI is a popular 'fix' for a variety of chronic infrastructure crises (e.g., combined sewer overflows, or CSOs). Therefore, it is important to examine GI facilities holistically as SETS to understand varied potential outcomes/unintended consequences of GI programs as they are increasingly deployed across the US. We acknowledge that the SETS framework currently struggles to avoid flattening social systems (as well as ecological and technological systems) to a one-dimensional variable, even though each domain should include a robust range of elements (Figure 1; and see Grabowski, Denton, Rozance, Matsler, & Kidd, 2017, for a critique and expansion of the SETS framework). But we find SETS framing useful in lining up usually disparate disciplinary variables to provide new, if limited, insights.

Here we focus on institutional dynamics as a key social element, which allows us to integrate political, financial, and cultural aspects of GI; however, we are limited in this work to the point of view of a singular group—institutions. We use the eco-techno spectrum to analyze GI programs in Portland, Oregon and Baltimore, Maryland and identify the definition and measurement knowledge systems' challenges embedded in municipal institutional dynamics. Our work is, therefore, an analysis of one aspect of the social challenges found across ecological and technological variation. Our results suggest that the eco-techno spectrum can serve as a framework to evaluate the institutional challenges facing innovation in infrastructure management across sectors, including transportation, energy, and water.

2. Ecological-Technological Hybridity and the 'Eco-Techno Spectrum' of GI Interventions

The concept of GI comes with significant conceptual baggage from the differing worldviews that invoke the term to accomplish different goals (Mell & Clement, 2019). Different stakeholders hold different ideas about both what GI *is* and what it *should do*. Conceptual mismatches are exacerbated by the overlap of GI with similar but distinct concepts, such as Nature-Based Solutions and Ecosystem Services (Escobedo, Giannico, Jim, Sanesi, & Lafortezza, 2019). Differing visions of GI are, therefore, contested in US cities attempting to build low-cost and sustainable infrastructures. For example, Finewood (2016) found that GI options were originally dismissed by engineers in Pittsburgh when completing a new stormwater management plan as knowledge claims regarding GI's effectiveness were not salient in the established engineering knowledge system. Non-profit and community groups, however, envisioned the social and ecological (beyond the technical) benefits GI could provide and contested the proposed all-grey-infrastructure plan demanding revisions that included GI.

Here, we develop the eco-techno spectrum as a platform to explore social-political questions of knowledge systems across grounded ecological and technological specifications. In particular, we focus on institutional dynamics as a key social system because there are important institutional barriers that manifest across the variety of facility types that are included in municipal GI programs and plans (Mell, 2013). For example, GI facility types range from small-scale, highly engineered facilities like bioswales and green roofs to large-scale parks, forest patches, and floodplains. In between are urban agriculture facilities, pocket parks, and greenbelts, as well as street tree networks. A primary distinguishing characteristic of GI across this variety is the explicit use (or mimicry) of ecological processes to provide utility services; biological elements are integrated to differing degrees with grey technological components to provide services, making GI facilities ecological-technological hybrids used in the service of social systems. This creates issues regarding physical and ecological functionality, but also exacerbates oft-overlooked social-political issues of management; each of these hybrids is managed by different jurisdictions with conflicting goals and missions, complicating the rhetoric of a singular GI program in any municipality. Municipal staff (planners, engineers, accountants, etc.) must navigate this complicated territory to finance, implement, and maintain GI systems.

The eco-techno spectrum works to categorize the ecological and technological variety of GI to better organize and specify such social barriers. The spectrum's base highlights the different degrees to which a GI facility includes biological entities (e.g., plants, microbes) as a designed component of the facility they constitute—this is the 'eco' part of the 'eco-techo' shorthand. There is more ecology on the left-hand side of the spectrum and more physical-mechanical technology on right-hand, or 'techno,' side of the spectrum (Figure 1). Other scholars have presented similar spectrums to examine aspects of GI, including Mell's (2013) use of Davies' "grey-green continuum" which highlights distinctions between facilities that are "visually green" (e.g., parks, grass) and those that are considered green because they are "sustainable" (e.g., bike paths, LEED buildings). Bell, Stokes-Draut, and McCray (2018) also propose a gray-green typology focusing more narrowly on stormwater management facilities, while the Royal Society Science Policy Centre's (2014) rejection of a grey or green binary recognizes a "hybrid" category of resilient infrastructure options. Finally, Childers et al. (2019) separates eco-techno hybrids along multiple continuums representing differing ecosystem features, including "blue" (i.e., water-based) and "brown" (i.e., soil-based) infrastructures as well as GI.

The eco-techno spectrum, therefore, builds on the recognized usefulness of continuums in exposing the ecological and technological nuances of GI efforts. The eco-techno spectrum differs from other efforts by projecting social (the 'S' in SETS) aspects of infrastructure across this platform. Because of this cross-epistemological framing, the eco-techno spectrum is well suited to explore the connections (and disconnects) between knowledge systems.

2.1. Operationalizing SETS for GI Research

The base of the eco-techno spectrum is designed to capture the diversity of technologies, jurisdictions, scales, and ecosystems that make up GI in current municipal programs. Heterogeneity of components, scales, and jurisdictions is not unique to GI, as nearly all infrastructural systems must cross epistemic and physical boundaries in their organization and management (Pinch, 2010; Star, 1999). However, GI represents a new assemblage of previously disparate groupings and component types which have not been traditionally viewed as 'infrastructure' in urban planning (i.e., plants are not typically viewed as infrastructure). The well-established epistemic categories (Bowker & Star, 1999) and standards (Lampland & Star, 2009) that have developed over time in municipal management to deal with cross-boundary issues of grey infrastructure are not germane to managing ecological processes. In fact, in most instances the ecological properties of GI are invisible to, or not fungible with, the epistemic community designing, constructing, or maintaining GI (Matsler, 2019). Therefore, understanding and addressing the knowledge systems challenges of GI efforts in cities today is critical to the realization of effective service delivery from this infrastructure 'fix.'

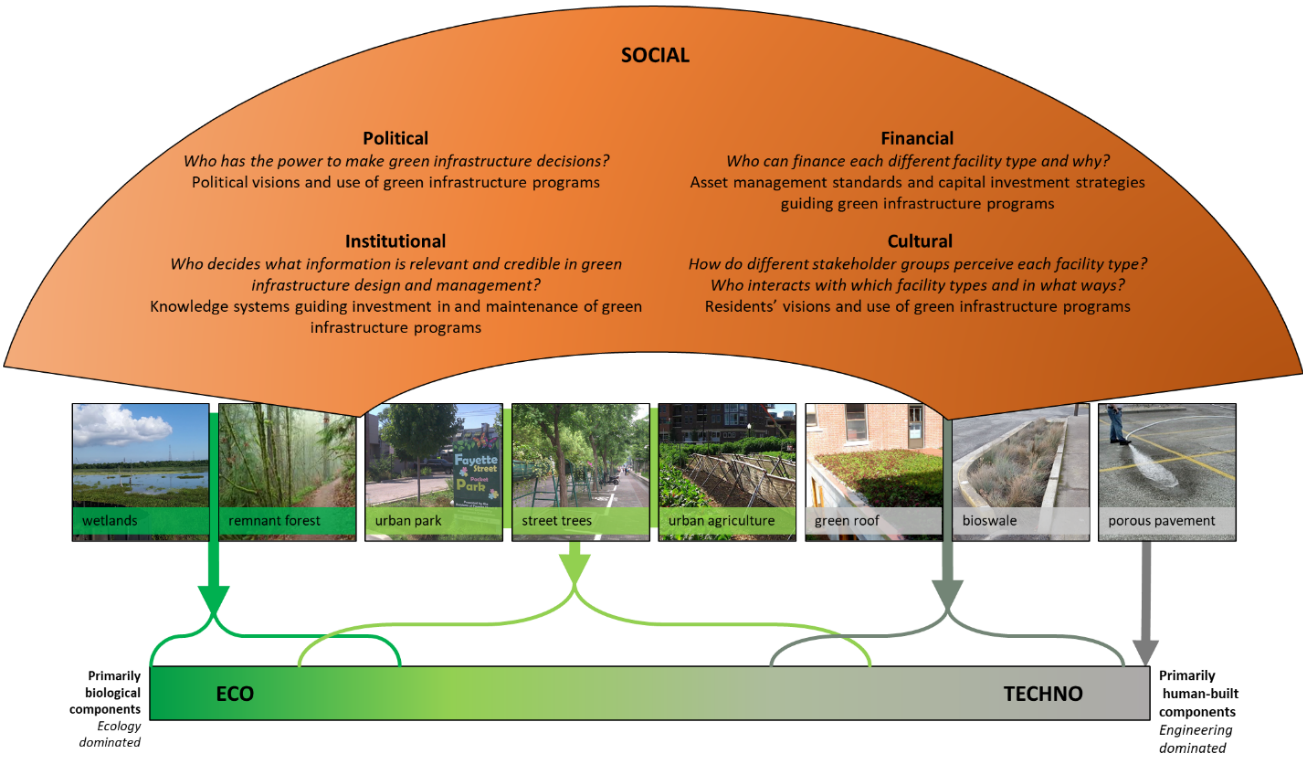

Figure 1. The eco-techno spectrum of GI organizes facilities by the proportion of the facility that consists of living, biological components vs. human-made, technological components. This forms a platform on which to connect salient social interactions with ecological and technological parameters, providing a unifying heuristic for operationalizing the SETS framework. The answers to specific social questions differ as one moves from 'eco' to 'techno' facility types, creating diverse social-institutional tensions across spectrum. Notes: Photo credits by Marissa Matsler (wetlands, urban park, street trees, bioswale), City of Portland (remnant forest, green roof), Create Commons (urban agriculture), and Milwaukee Metropolitan Sewerage District (porous pavement). Source: Adapted from McPhillips and Matsler (2018) and Matsler (2019).

3. Emergent Knowledge System Challenges

3.1. Definitional Challenges

The hybrid make-up of GI facilities does not fit neatly into the jurisdiction of any one municipal department or agency. The divergent goals and missions of these managing authorities has led to differing definitions of GI within cities. Therefore, the development of cohesive city-wide GI strategies (including facility design, implementation, and maintenance standards that work with existing land-use plans) is not straightforward; it requires the reconciliation of multiple knowledge practices across municipal departments.

While the specific definition of GI varies geographically (Mell & Clement, 2019), it is generally understood to encompass networked greenspaces that provide ecosystem services. Depending on the institution, however, the services and facilities included in the definition of GI can be quite different. For example, Benedict and McMahon's (2006) definition of GI stresses conservation of natural areas: "Green infrastructure is…an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations" (p. 5).

From this perspective, GI is a win-win land-use solution with an explicit focus on environmental gains. To the institutions that use this definition, GI represents preserved, conserved, or restored *nature*.

Alternatively, institutions like the US Environmental Protection Agency (EPA) focus on the stormwater management benefits of GI and are often indifferent to the natural character of facilities, allowing engineering solutions to be a major focus of the concept: "Green infrastructure is a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits….At the neighborhood or site scale, stormwater management systems that mimic nature soak up and store water" (EPA, 2015).

Cost-effectiveness and resilience in addressing regulatory compliance issues are unsurprisingly central in definitions from regulatory institutions, with habitat restoration/conservation seen as a co-benefit. Facilities within this framing mimic the functions of natural systems, rather than providing these functions through restoration or conservation of ecosystems. This framing emphasizes *technology* over ecology.

The eco-techno spectrum helps expose a tension inherent in these differing definitions as each focuses on different facility types: Stormwater management facilities are nearly all found on the 'techno' side of the spectrum, whereas restoration and conservation facilities are found on the 'eco' side.

3.2. Measurement Challenges

GI facilities rely on ecological functions that emerge from the combination of complex and relatively poorly-understood biological actors, instead of narrowly-defined and precisely measured physical functions that emerge from the well-understood mechanical components of grey infrastructure. The combination of biological entities in GI facilities is often novel (Hobbs, Higgs, & Harris, 2009), meaning existing ecological theory may not apply to the community assembled in a GI facility. This reliance on unpredictable ecological function makes it difficult to measure or predict the performance of GI facilities, complicating estimates of total service delivery.

The challenge of measuring the performance of hybrid systems stems primarily from an epistemological tension. Different epistemic communities measure services in different, sometimes conflicting, ways. An epistemic community is "a network of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area" (Haas, 1992, p. 3). Engineers represent an epistemic community with a strong 'authoritative claim' over the knowledge relevant to infrastructure performance. This epistemic community does not currently have the tools to fully recognize ecological knowledge in facility performance metrics.

A major challenge in reconciling ecological and engineering epistemic communities arises from the variable and dynamic aspects of ecological systems themselves. Indeed, a major theme in the basic science of ecology over the past 20 years has been a focus on 'disequilibrium' and the 'the flux of nature' rather than earlier ideas about 'equilibrium' and a 'balance of nature' (Wu & Loucks, 1995). Ideas about stability, resistance, and resilience in ecological systems first emerged in the 1960s and centered on the ability of these systems to maintain their structure and function in the face of disturbance, or to recover quickly from disturbance (Bormann & Likens, 1994; Holling, 1973; Odum, 1969). The concept of ecological thresholds, which emerged in the 1970s, is based on the idea that ecosystems can have multiple 'stable' states, depending on environmental conditions (Beisner, Haydon, & Cuddington, 2003; Holling, 1973).

While ideas about stability and resilience have helped environmental scientists to conceptualize ecosystem dynamics, they have been difficult to operationalize and use in practical management of actual environments (Groffman et al., 2006). Current active areas of research include developing an ability to monitor and predict where and when state changes are likely to occur, how to manage for resilience, and how to reverse state changes. There is a clear need to resolve these issues within the epistemic community of ecology before these concepts can be used to design and implement GI.

4. Methods

We examined the various perspectives of GI (what it *is* and what it *should do*) at work in municipal administrative structures of ongoing GI planning and implementation in Baltimore, Maryland and Portland, Oregon to reveal current knowledge systems' challenges. Comparative case study methods were used—following Yin (2014)—from 2015 to 2017. Important contextual differences between the two cities, including their socioeconomic make-up, racial identity, and regulatory environment make them ripe for comparison (Table 1). Results presented in this paper were derived from semi-structured interviews conducted with professionals involved in the planning, construction, financing, and maintenance of GI programs in each city. These professionals represented a range of disciplinary backgrounds and administrative roles (Table 2). A total of 42 interviews were conducted: 22 in Portland and 20 in Baltimore. Because the primary focus of this work is knowledge systems of municipal government institutions, most interviews were done with city staff from various departments. However, in Baltimore, it was necessary to expand interviews outside of city staff because most GI implementation was conducted by NGOs at the time of data collection. In every interview conducted with municipal staff in Baltimore at least one non-profit (and usually upwards of three) was mentioned as an instigator, an implementer, or a partner in GI development; therefore, we were confident in including multiple interviews with NGO staff in Baltimore. In contrast, most design, implementation, and maintenance of GI facilities, and the knowledge production supporting those actions, was found in-house at the City of Portland; private firms and NGOs were not mentioned in interviews. Therefore, though some conversations occurred with private consultants and non-profit staff in Portland, we were confident confining formal interviews to city staff. Recorded interview audio was transcribed by a third-party service. Transcripts were analyzed using ATLAS.ti following Friese's (2014, 2016) coding techniques. Discourse analysis was employed to categorize and interpret results (Hajer & Versteeg, 2005).

Interviews were chosen as the primary data collection method in this study because of their ability to provide robust descriptive data regarding how knowledge systems around GI work *in situ*, something that document analysis alone cannot reveal. As a relatively newly recognized infrastructural system, institutional dynamics of GI are emergent and therefore well-suited to inductive methods, rather than deductive methods that help refine and/or challenge already defined systems. Interviews, however, have limitations. While interview subjects can provide perspectives on their organizations and social networks, the data gathered is limited to the perspective

Table 1. Case study SETS characteristics, highlighting two long-term GI programs in different social, ecological, and technical contexts.

Context	Baltimore	Portland
Social		
Population (2017)	610,481	647,924
African American	63%	6%
White	31%	76%
Median Income (2017)	$47, 131	$63,974
Growth	Shrinking, currently plateauing city with large amt of vacant and abandoned lots	Growing city with increasing housing market pricing out many residents
Governance	Strong-mayor, Mayor-Council Form Government	Weak-mayor, Commission Form Government
Equity & Justice	High poverty rates and racial segregation	Large and growing homeless population
Technology		
Sewer system	Separated storm and sanitary sewer	Combined storm and sanitary sewer (some areas separated sewer)
Regulations		
National Pollutant Discharge Elimination System (NPDES) Permit	MS4 & SSO program	MS4 & CSO program
EPA Consent Decree	2002	1991
Total Maximum Daily Load (TMDL)	Trash, Nitrogen, Total Suspended Solids	Phosphorus, Total Suspended Solids
Ecological		
Avg precipitation	41.9” in 116 days	43.5” in 164 days
Rainfall patterns	Short, intense rainstorms/thunderstorms	Continuous, low intensity rainfall
Urban tree canopy cover (2018)	27.4%	29.9%
ParkScore Ranking (2020)	58/100 Largest US Cities	6/100 Largest US Cities
Biome	Temperate Forest	Boreal Forest

Notes: Population and Median Income estimates from US Census Bureau (2017, 2019). Urban Tree Canopy estimates in Portland from Ramsey and DiSalvo (2018) and Baltimore from Department of Recreation & Parks (2018). ParkScore ranking from Trust for Public Land (2020).

Table 2. Breakdown of interviewees by city and professional role.

Participant Professional Role	Baltimore	Portland
Environmental Science & Management	5	7
Finance/Accounting	2	7
Engineering	4	3
Landscape Architecture	2	1
Planning	3	2
Administration/Project Management	3	1
Public Outreach	1	1
Total # of Participants	20	22

of the subject pool. We attempt to mitigate this by identifying a broad group of practitioners across Portland and Baltimore to confirm agreement and overlap on approaches and processes, though we acknowledge that some bias still exists. Future GI knowledge systems work should expand datasets to include additional methods, such as surveys (for example, social network analysis of institutional actors), as well as work to include the perspectives of residents and community groups.

5. Case Study Results

5.1. Definitional Knowledge System Challenges

All interviewees were asked: "What is your working definition of GI?" There were two generally agreed upon aspects across all interviewees in both cities. First, GI facilities include living components (not just 'sustainable' components):

> I think anything that's just planted with vegetation, whether it's native or nonnative vegetation, and something that's a dynamic system that is managed as such. (Portland, Bureau of Environmental Services [BES] staff)

> To me, green infrastructure is natural. It's…trees, vegetation; especially when that's replacing impervious concrete and grey infrastructure….It's green because it's a natural feature, like a native plant. It is based on a living organism and a local ecosystem. (Baltimore, non-profit staff)

But it was also clear that the urban nature that makes up GI is not just any nature. GI refers to nature that provides services; this type of nature was what made it 'infrastructure':

> It is natural systems that are being used to support services that we provide. (Portland, Office of Management and Finance [OMF] staff)

> Anything that you could provide traditionally in a built way that you're instead providing in a green type of way. (Baltimore, Office of Sustainability staff)

> Personally, I was interested in using soil and plants to slow down the runoff, to filter the runoff, and to try to infiltrate and remove as much of the runoff, as close to its source as possible. I think that's pretty close to our official definition. (Portland, BES staff)

> Streams, trees, green roofs. I think about everything about dealing with surface water. (Baltimore, Department of Public Works [DPW] staff)

Second, GI was overwhelmingly defined as multifunctional, providing a wide range of co-benefits including urban heat island mitigation, stormwater management, air purification, water treatment, biodiversity, traffic calming, habitat, social cohesion, and more. This was summed up succinctly by a Baltimore DPW staffer who responded "oh everything" when asked what services are provided by GI.

However, beyond these two nodes of agreement, there was significant differentiation in the definition of GI. Definitions were more strongly differentiated across departments/institutions within each city than between cities. For example, both Baltimore Recreation and Parks Department and Portland Bureau of Parks and Recreation focused on an expanded network view of GI which included forest patches and natural areas as facility types; these are facilities found on the 'eco' side of the eco-techno spectrum. In contrast, utility departments like BES and DPW focused instead on modular stormwater management facilities (e.g., bioswales) found on the 'techno' side of the spectrum.

The eco-techno spectrum therefore points out that problem-framing differs across departments within a city, rather than between cities; this suggests that technological and ecological differences between the cities (e.g., combined vs. separated sewers) are not driving problem-framing as much as the jurisdictional mandate for specific departments to provide specific services (i.e., the demand for stormwater management and recreation services more generally in each city). This highlights the importance of socio-institutional aspects of GI service delivery to GI program development.

5.1.1. Challenge or Opportunity?

Another differentiation between municipal departments in both cities was their response to the broadness and ambiguity of GI as a term. A quote from a staffer at the Baltimore Recreation and Parks Department sums up the overarching sentiment: "It's such a broad term, I mean, I don't think I've ever heard a textbook definition that everyone has agreed upon." The definitions provided by other interviewees reflected this broadness, describing a range of facilities that span the eco-techno spectrum.

The broadness of GI definitions was described alternately as a positive or a negative feature. Sentiments towards definitional broadness differed by department and organization type, not by city. For example, staff at DPW expressed concern over the implications of definitional ambiguity for the stormwater management budget:

> We focus on [stormwater] because, when it becomes too broad, green infrastructure suddenly becomes greening. Suddenly it becomes let's spend DPW stormwater fee utility money…to do community gardens…[or] any number of things that really have little to no benefit for stormwater. So we have to be very careful using the terminology and managing our funds….There are people within city government and

> outside city government that feel like "oh, we have now this pot of money that we can use for any type of greening" and…we can't because our goal is to meet the MS4 [municipal separate storm sewer system] permit. (Baltimore, DPW staff)

However, other interviewees saw the broadness of the term in a positive light. Staff in coordinating departments and agencies such as the Portland Bureau of Planning and Sustainability and the Baltimore Office of Sustainability expressed that they were encouraged by the "wiggle room" available from ambiguity; it allowed them to connect more stakeholders to projects. This difference in views of specificity represents a knowledge system challenge. One department 'knows' infrastructure within narrow physical and economic tolerances that must be met for appropriate and legal function; it has knowledge practices (for example protocols for quantifying stormwater run-off) that fit a single-service, 'techno' infrastructure vision. Other departments 'know' infrastructure as something that must accommodate a wide range of community needs; they have knowledge practices (for example norms of inclusivity and protocols for gathering multiple qualitative points of view at public outreach events) that fit a wider, multiple-benefit, 'eco' infrastructure vision. This contrast in knowledge practices is common within cities (Friedmann, 1993), but here presents novel challenges.

An additional challenge, expressed across all groups, was the lack of understanding or definition of GI facilities as actual 'infrastructure' by city residents and property owners. In Baltimore, it was challenging for facility inspectors to keep up with new property owners:

> People don't even know what they have. With green infrastructure in particular, they look at it and all they see is "I've got a garden. If I let the weeds grow in the garden, so what?" They don't know what they're supposed to do….We find a lot of times our inspections are re-informing the property owners of what they're supposed to do. (Baltimore, DPW staff)

In Portland, BES faced a lawsuit in 2014 from ratepayers arguing that GI was part of "mission creep" within the bureau. They called spending on green streets (a GI facility type) a "misappropriation of sewer funds" spent on "luxury greening projects" rather than 'real' sewer projects (Law 2014), displaying the lack of recognition of GI as 'infrastructure' on the part of plaintiffs.

In summary, we found that definitions differed most between departments within cities. The ambiguity around GI produced legal and budgeting challenges for engineering-based departments while a broad definition was a boon to Planning and Parks departments in both cities. When we project these findings onto the eco-techno spectrum (Figure 2), we can begin to relate specific facility types with different definitions of GI. Misinterpretations of the term by those with alternate definitions of GI can lead departments to act like "ships in the night" (Vogt, 2018), missing opportunities to provide more effective service delivery and outreach, when facility types are left implicit in planning efforts.

5.2. Measurement Knowledge System Challenges

Accurate performance metrics are important to infrastructure management. However, it was apparent from

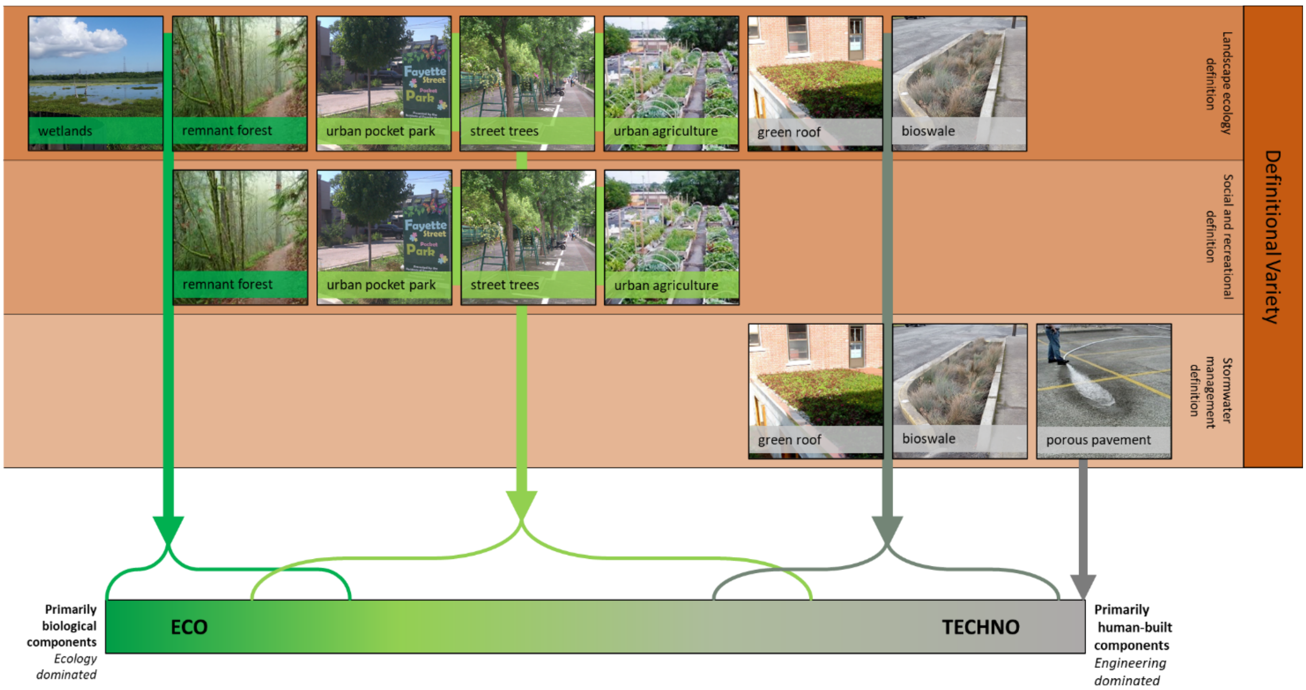

Figure 2. Facility types most commonly associated with, but usually implicitly, three distinct definitions of GI.

interviews that performance metrics were influenced by definitions of GI and the mission of the institution implementing the facility. Here, particular attention was given to assessment of biological entities in GI facilities. Plants used within facilities are often described as having little or no influence on the hydrologic functionality of a facility. A more nuanced understanding of this view came out in interviews: While all interviewees in this study perceived plants as having a role in facility function, none knew of metrics that were regularly employed to assess that functionality. As one engineer described it, it depended on what service was being measured:

> You could easily support that idea [that the plants are only 'window-dressing'] by picking one of those analytes out. Like if you said, hey, let's focus on the metals or the solids or something, maybe the plants aren't that critical because it's really the media, or it's that filter, that's stopping that material from reaching…the creek or to the street storm sewer. However, they [the plants] reduce the heat island effect, they help temperature, they help uptake of certain other things like nitrates…oils and greases tend to get trapped in vegetation at a certain rate….So, it depends on what you're talking about. (Portland, BES staff)

In both Baltimore and Portland water quantity and quality were highlighted in the discussion of measurement. Nearly all regulatory requirements revolved around these metrics, making them the most discussed and most well-developed measurements across all groups:

> It's all rooted in hydrology. So, it's looking at here's what a site would look like hydrologically if it was all wooded and forested. And then your objective is to build buildings on it but mimic that natural hydrograph. So as long as you can do it, you can fit as many buildings on there as you want, as many roads, if you can capture and treat the run off and mimic that natural hydrograph, then the State would give you a check mark, you have done your job. (Baltimore, private firm staff)

> [Water] quantity is a real important aspect and benefit of green infrastructure…and that's what the manual is designed [for]. There's other benefits to green infrastructure, that's recognized, but that's not the driver for us as far as requiring green infrastructure. (Portland, BES staff)

The focus on water quantity and quality has meant that less attention has been given to other services (like biodiversity, social cohesion, air quality improvements, well-being, etc.). These other services were discussed by interviewees (and are often touted by GI advocates in general) as important co-benefits of GI; but actual mechanisms to integrate these services into level-of-service or performance metrics was not reported in either city. Delivery of such services was mostly assumed by interviewees based on studies indicating the potential for GI to provide these services.

Again, when we project these findings onto the eco-techno spectrum (Figure 3), we can relate different metrics with different facility types (i.e., different ecological and technological parameters). As discussed in the background, metrics evaluating ecological functions of GI facilities are currently imprecise while hydrologic functions are well known. Primarily, hydrologic functions are used as metrics for 'techno' facilities and we can see that as we move toward 'eco' facilities that less precise ecological metrics dominate. This projection therefore begins to show potential differentiation within the suite of services provided across the concept of GI; there is a need to address and plan for such variation, rather than lumping all GI into a singular concept.

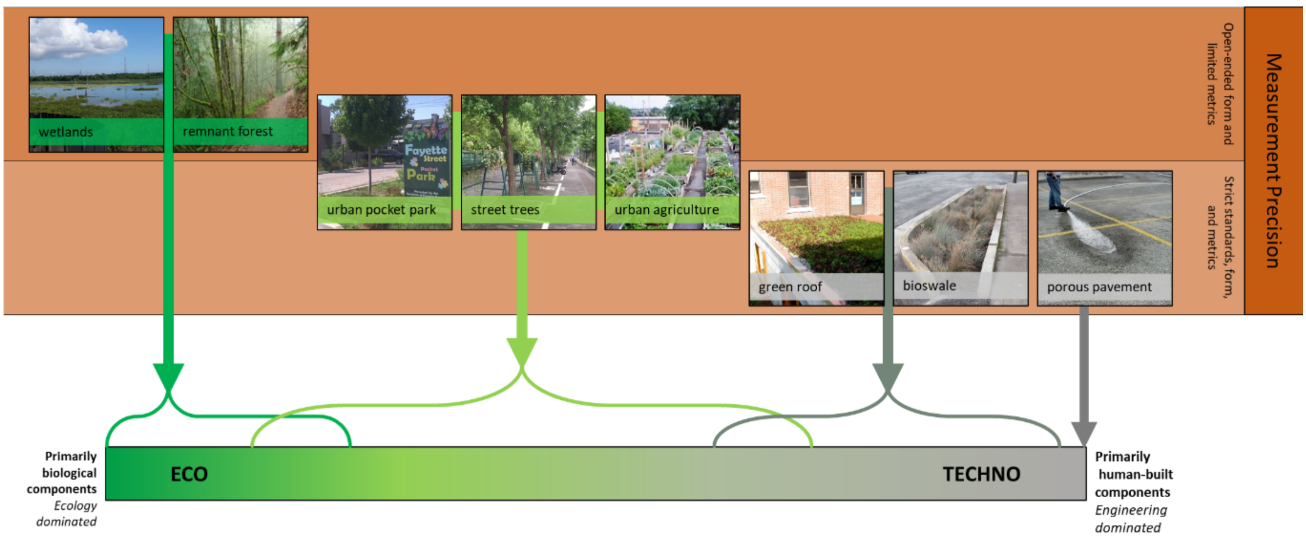

Figure 3. Precision and focus of metrics and standards vary across the eco-techno spectrum.

5.2.1. Emergent Work-Arounds?

To work around measurement challenges, interviewees described institutional changes and adjustments that were primarily focused within a department/bureau. Performance metrics are tied closely to the mission and public obligation of each department (i.e., CSO reductions by BES, or recreation obligations of the Baltimore Recreation and Parks Department) and must reflect the progress that the institution is making towards its level-of-service goals. This contrasts with the definitional challenges and changes discussed above which are mostly in regards to communication across departments and communities.

First, both cities mentioned the extended use of asset management software to track GI facility performance through time. Initially, GI facilities were not included in BES or DPW's databases. At BES, as the number of curb side bioswales grew over time, they were added to the database, but the biological aspects of the facilities were not included. Staff now say that more detailed information regarding the condition of these biological entities is being tracked via their asset management software and that this tracking has become more granular:

> It used to be that, if they went up to do maintenance, and that was a project that had…20 Green Streets [bioswales], they would all be lumped into one entry….Now they're able to actually pinpoint: "Well, 18 of those 20 facilities were easy, and these 2 here were the hard ones, that had a lot of sediment, or had problems with plant coverage," or what have you. It allows us to look a little more closely at patterns and maintenance activity, and that's certainly a new focus. (Portland BES staff)

Increased tracking of maintenance activities and facility condition will ultimately feedback into the design and implementation of GI in Portland, making the selection of *what* to measure an important decision point in this knowledge system. It is important to note that the generation of new software is ideally a linear process that follows the definition of needed functions and the development of indicators of those functions. However, municipal practice is far from ideal and this example highlights how the use of software can evolve in practice.

In Baltimore, a measurement challenge emerged from projects built by non-profits that did not have "as-built" documents. In order for a GI facility to count towards fulfilling the city's regulatory commitments of their MS4 permit, it needs to be assessed by an engineer as it is being built to determine how closely the designs for the facility match what is actually built on-the-ground. Without this documentation, non-profits were building projects that were not fungible with city government knowledge systems.

To address this measurement challenge, a collaborative process has begun in Baltimore where non-profits work directly with funders to earmark funds for the completion of as-built documents, and DPW contributes funds to retroactively commission as-built documents on some existing facilities. In this way, DPW can use these facilities in meeting the city's MS4 permit:

> [The State of Maryland Department of Natural Resources] was not providing funding for a group like Parks & People [a local Baltimore non-profit] to do an as-built, so we all got together and said: "There's this disconnect, right?" (Baltimore DPW staff)

> If you want to meet the intent of the money you need to include funding for as-builts so they can be transferred to the city as credits. So facilities that have already been put in…now we are developing a MOU [memorandum of understanding] with the City, for projects that you can go back and say "Yes, this is the project that happened." (Baltimore, non-profit staff)

Both non-profit and the city staff expressed relief that this process was moving forward. The tension between the institutions' knowledge systems is gradually easing as they find ways to mutually support one another in GI development: "We are in the process of going through…[and] transferring credit to the city. It makes you feel good that you are making change" (Baltimore, non-profit staff).

6. Discussion

6.1. Competing Visions

When examining GI definitions in Baltimore and Portland, we found evidence for the use of both greenspace-network (Benedict & McMahon, 2006) and stormwater-focused (EPA, 2015) visions. While a dominate vision was not detected in either city, it does appear that these two visions integrate and compete in different ways in the two contexts. Parsing out these visions across degrees of ecological and technological hybridity along the eco-techno spectrum allowed us to see which definitions and metrics are most likely to encourage different facility types or services, differentiation that is usually implicit in planning for GI as a whole in cities. By adding this granularity, we can begin to make explicit the embedded assumptions about facility types and the services they provide in planning processes; this mitigates confusion and unmet promises of incorrect assumptions.

Primarily, we observed knowledge practices dictated by regulations influencing the interplay of GI visions. In Portland, a federal mandate to address CSO violations was the initial driver of GI development. Because this required managing water quantity (i.e., keeping stormwater out of the combined sewer system), a stormwater-focused way of knowing GI emerged in Portland. Without a CSO regulatory push, Baltimore's primary driver was Chesapeake Bay-wide efforts to address water quality issues. Baltimore's MS4 permit and TMDL challenges have motivated solutions focused on forest patch enhancement and restoration where impervious surface is removed to restore natural hydrologic regimes. The facility types encouraged by this type of regulation are more easily integrated in a larger, regional green network vision of GI. However, facilities from across the eco-techno spectrum are built in both cities, showing that the negotiation of definitional and measurement contestations regarding GI does not result in uniform adoption of one vision or the other.

In both cities, technological differences initially appear to have the most influence on GI investments and definitions. The presence of separated (Baltimore) or combined (Portland) sewer systems dictated the type and severity of the regulatory violations in each city, driving the adoption of different types of infrastructure 'fixes.' But, parsing groups within each city, we find that municipal knowledge systems show differentiation within, or in spite of, this overarching regulatory framework. The tensions between the knowledge systems of engineering, parks/recreation, utility, and planning departments were often more important than technological differences.

Why is it important to understand what and how visions dominate in a city? The knowledge practices that support more 'eco' facilities or more 'techno' facilities to be built create new barriers to specific ecosystem services and to the equitable distribution of such services. For example, stormwater problem-framing of 'techno' facilities amplifies water quantity and quality management functions at the expense of other important benefits like nutrient cycling, recreation, or air filtration, among many others. This seemingly apolitical technical decision can cause very real social consequences by precluding the provision of other important services on-the-ground. As Bowker and Star (1999, pp. 5–6) put it: "Each standard and each category"—understood as knowledge systems' practices in this study—"valorizes some point of view and silences another." We need to be explicit about what and who is being silenced by current stormwater-focused GI planning.

6.2. Interactions across the Eco-Techno Spectrum

GI facility types that span the entire eco-techno spectrum are present in both cities. While not every city department, non-profit, or company recognizes the entire spectrum as GI, all points along it are recognized by at least one institution in each city. It is important to reiterate here that each definition of GI seems to point towards a different end of the eco-techno spectrum. While GI is often described in policy and outreach as a singular concept, there is significant variability regarding the services provided by 'eco' vs. 'techno' facilities. This is most apparent when looking at the extremes of the spectrum: Porous pavement is GI because it mimics natural hydrology and provides water infiltration services, but it would be strange to attribute spiritual or cultural values of nature more generally to the parking lots and driveways that it creates. As one moves along the eco-techno spectrum away from porous pavement and towards 'eco' facilities like forest patches, the number and scope of services provided can increase; but service delivery depends on initial design parameters, as well as ongoing maintenance activities. The eco-techno spectrum organizes these differences more systematically than a simple 'grey' vs. 'green' infrastructure dichotomy. While 'grey' vs. 'green' was an important starting point, we now need greater granularity to effectively plan GI systems. The eco-techno spectrum, and frameworks like it, begin to do this work.

Institutionally, it is useful to note that protocols stemming from regulatory structure and norms inherent in economic status were observed differentiating whether an institution opted to build more 'techno' or more 'eco' leaning facilities. For example, Baltimore faces budget shortfalls. While cheaper than many grey infrastructure systems, GI facilities on the 'techno' side of the eco-techno spectrum are still expensive. Without a regulatory push demanding money be spent on this problem, the knowledge claims indicating the multiple benefits of most 'techno' GI solutions do not sway a cost-benefit analysis to justify their implementation in Baltimore. In fact, Portland BES is now dealing with a similar issue as they turn their concentration from CSO watersheds to MS4 watersheds:

> Now that we've done the first phase of our combined sewer work…we've started to put more attention into the separated parts for our system, the MS4 system….The questions become a little more difficult, it's not quite as easy to do an apples to apples comparison of grey and green anymore. If you're dealing with water quality issues, how much did you spend to remove a pound of total suspended solids out of the system? Those questions aren't quite so clear-cut. (Portland, BES staff)

As this turn has progressed, institutional norms in Portland have moved towards an integration of facilities across the eco-techno spectrum, with a focus on more comprehensive planning integrating both stormwater and network visions:

> I call what we do, little 'g,' little 'I,' green infrastructure, and then there's capital 'G,' capital 'I,' Green Infrastructure, which would include all of the interconnected, larger ecosystem type things that come in, so really our forests, and then natural areas and stream corridors that we still have that need to be protected, and interconnect those things. (Portland BES staff)

By looking across the challenges highlighted by the eco-techno spectrum, Portland's movement towards integration can be expected to present new barriers and concerns to GI planning. Standards and prescriptive codes are likely necessary for 'techno' facilities, however this will limit development of 'eco' facility types that lack metrics and are not normally included in stormwater management definitions. Awareness of this inertia towards uneven development across the eco-techno spectrum can focus planning processes on rebalancing effort to be sure a full spectrum of greenspace facilities are built, conserved, and maintained to ensure all expected services are provided by the GI system.

7. Conclusion

Municipalities are increasingly looking towards GI to sustainably 'fix' a wide variety of infrastructure crises they face. However, this research has shown that GI planning runs into institutional challenges that limit its ability to provide needed benefits. GI efforts in both Portland, Oregon and Baltimore, Maryland provide examples of knowledge systems' challenges faced by urban planning processes attempting to integrate GI. Our results suggest that viewing GI facilities along an eco-techno spectrum helps to make explicit the different plans for, and outcomes of, these facilities across usually siloed epistemic communities. By adding granularity and specificity to the SETS relationships across different forms of GI, the eco-techno spectrum can help municipal actors and researchers better recognize and account for the multi-functional nature of GI. This can lead to better articulation of the financial and institutional responsibilities of different GI approaches and help municipalities choose the most appropriate facility types to do the job they need.

GI facilities explicitly integrate ecology and engineering in their design, but arguably all infrastructures can be viewed as eco-techno hybrids. By projecting social, cultural, political, financial, and institutional factors onto a more granular set of ecological and technological parameters (rather than a simple grey–green dichotomy), we begin to see more explicit differences in service delivery from infrastructural systems built using different problem frames and visions. Revealing and acknowledging these differences is a concrete step towards planning more effective GI programs specifically and more robust infrastructure crisis 'fixes' in general.

Acknowledgments

We would like to acknowledge and thank practitioners in Portland and Baltimore for sharing their time and expertise with us, providing deep insights to this work. This material is based upon work supported by National Science Foundation IGERT Grant #0966376: "Sustaining Ecosystem Services to Support Rapidly Urbanizing Areas." Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Conflict of Interests

The authors declare no conflict of interests.

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COGITATIO

Urban Planning (ISSN: 2183–7635)
2021, Volume 6, Issue 1, Pages 63–74
DOI: 10.17645/up.v6i1.3518

Article

More Than Open Space! The Case for Green Infrastructure Teaching in Planning Curricula

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Submitted: 29 July 2020 | Accepted: 10 September 2020 | Published: 26 January 2021

Abstract
Since the mid-1990s, the concept of Green Infrastructure (GI) has been gaining traction in fields such as ecology and forestry, (landscape) architecture, environmental and hydrological engineering, public health as well as urban and regional planning. Definitions and aims ascribed to GI vary. Yet, agreement broadly exists on GI's ability to contribute to sustainability by means of supporting, for example, biodiversity, human and animal health, and storm water management as well as mitigating urban heat island effects. Given an acknowledged role of planners in delivering sustainable cities and towns, professional bodies have highlighted the need for spatial planners to understand and implement GI. This raises questions of what sort of GI knowledge planners may require and moreover by whom and how GI knowledge and competencies may be conveyed? Examining knowledge and skills needs vis-à-vis GI education opportunities indicates a provision reliant primarily on continued professional education and limited ad hoc opportunities in Higher Education. The resulting knowledge base appears fragmented with limited theoretical foundations leading the authors to argue that a systematic inclusion of green infrastructure knowledges in initial planning education is needed to promote and aid effective GI implementation.

Keywords
curricula; green infrastructure; higher education; planning profession; spatial planning

Issue
This article is part of the issue "Urban Planning and Green Infrastructure" edited by Paul Osmond (University of New South Wales, Australia) and Sara Wilkinson (University of Technology Sydney, Australia).

1. Introduction

Since the mid-1990s, the concept of green infrastructure (GI) has gained increasing traction in built and natural environment associated fields. These include ecology, forestry, (landscape) architecture, environmental and hydrological engineering, public health, and urban and regional planning. Depending on subject and geographical context, the definition of what constitutes GI varies as do the benefits perceived from GI (Benedict & McMahon, 2001). For example, American Rivers, a US based conservation organization, defines GI as "an approach to water management that protects, restores, or mimics the natural water cycle" (American Rivers, n.d.). As such it offers a cost-efficient approach to meet the requirements of the national Clean Water Act (Emmett Environmental Law & Policy Clinic and the Environmental Policy Initiative, 2014). The Pennsylvania Land Trust, meanwhile, suggests that GI acts as tool for smart growth and conservation (Benedict & McMahon, 2006). Moving beyond water and land management, the European Commission (2020) stresses the multifunctionality of GI and its value in terms of ecosystems services such as air quality enhancement, climate change mitigation and adaptation, and citizens' health and wellbeing by providing leisure spaces. Differing definitions aside, however, GI is consistently conceived as a strategically planned network of natural and semi-natural areas. There is broad agreement that GI offers tangible benefits for society and the environment through its contributions to a sustainability transition of urban and peri-urban areas (e.g., Tzoulas et al., 2007). In fact, Benedict and McMahon (2002), coming from a landscape architecture and planning background, go as far as labelling GI as a life support system for communities, which not only contributes to but is essential for environmental and economic sustainability.

Given planners' role in delivering sustainable development (e.g., Royal Town Planning Institute, 2015; UN Habitat, 2009;), they are seen to hold a key role—alongside landscape architects and environmental engineers—in developing, designing and implementing GI on the ground. In the UK, the Royal Town Planning Institute's briefing explicitly notes that "the importance for planners to understand and apply a green infrastructure approach has never been greater" (Royal Town Planning Institute, 2013, p. 2). Green infrastructure and its material manifestation as in green roofs and walls, green belts, parks or rain gardens and so forth are more and more integrated in statutory as well as informal planning instruments such as zoning plans, resiliency and climate change mitigation strategies at city level, in strategic spatial plans, or land use plans (e.g., Hansen, Rall, Chapman, Rolf, & Pauleit, 2017). The coordinating role identified for the planning profession implies a need for substantial (new) knowledge and skills in regional design and policy measures that promote GI development. This also includes knowledge of how to effectively work in partnership with different local and regional actors across disciplinary and administrative boundaries (Hansmann et al., 2016) and engage with communities (Zuniga-Teran et al., 2020).

Much literature on GI consists thus far of a proliferation of reports from industry (e.g., UK Green Building Council, 2015), non-profit organizations (The Earth Genome, 2016), and government and supragovernmental bodies (e.g., Environmental Protection Agency, 2014; European Commission, 2016; Natural England, 2009) promoting the idea of building, enhancing, investing and maintaining green infrastructure. Themes expressed by these documents are mirrored by built environment professional bodies (in planning, landscape architecture or engineering) and research projects that offer practical guidance and training for practitioners on GI design, valuation and implementation (e.g., American Planning Association, 2007; Australian Institute of Landscape Architects, 2015; Hansen et al., 2017; Royal Town Planning Institute, 2013; UK Green Building Council, 2015). Two different strands of GI practice display prominence (although within and between these, different perspectives exist): An emphasis on biodiversity and ecology of habitat networks and a technological and engineering focus, for example, green roof design or sustainable drainage systems. In addition, several comprehensive overview texts such as the *Handbook on Green Infrastructure* (Sinnett, Smith, & Burgess, 2015), the *Routledge Handbook of Ecosystem Services* (Potschin, Haines-Young, Fish, & Kerry Turner, 2016) and *Green Infrastructure Planning: Reintegrating Landscape in Urban Planning* (Mell, 2019) have been published. Interestingly, while Sinnett et al. (2015) make reference to the potential educational benefits afforded by GI such as informing the public on nature, biodiversity, and also the need of providing skills for those caring for green infrastructure, the discussion of the type of GI education required for professionals such as planners, engineers or urban administrators remains sparse. Manley (as cited in Sinnett et al., 2015) alludes to the need of educating professionals. However, her contribution focuses on designing and implementing inclusive environments primarily, while emphasizing secondarily that this also applies to parks and green public spaces. More recently, training needs in operationalising GI approaches and instilling multi-criteria GI thinking that overcome silo-mentalities were identified by Lennon, Scott, Collier, and Foley (2016), and Meerow and Newell (2017).

Accepting the relevance of GI to planning sustainable cities and focusing on English-language provision, this article critically queries the training and educational needs for the planning profession that may arise from the growing GI discourse and considers how these might be addressed. In terms of education for planning, both university level programmes and continued professional development contribute to address skill and knowledge needs. Continued professional development tends to focus on praxis and technical issues shunning less tangible but no less important conceptual and theoretical aspects. The latter tend to be a prerogative of university level education.

In planning education curricula, GI may be perceived by some as old wine in a new bottle—merely requiring a relabelling of pre-existing topics (e.g., open space planning and protection) which have been a part of planning education for decades to reflect new *en vogue* terminology. In some institutions, in fact, planning courses were first started in landscape architecture faculties (Silver, 2018). Others—including the authors of this article—consider designing, planning and implementing GI a sufficiently distinct knowledge field that warrants a more explicit inclusion in planning education. The article develops this rationale in three sections. First, examining the relationship between green/open space and green infrastructure from a planning perspective reveals similarities and differences in terms of knowledge needs. Second, the article then presents findings from a review of GI knowledge provision. Third, outcomes suggest that a more systematic and integrated, interdisciplinary coverage of GI at degree level would be of merit to progress a sustainability transition by working more effectively toward implementing Sustainable Development Goals of the UN (UN, 2015) and the New

Urban Agenda (UN Habitat, 2017), which was ratified by the UN Conference on Housing and Sustainable Urban Development (Habitat III).

2. Green Infrastructure Vis-à-Vis Green/Open Space Planning

Spatial, urban and regional planning always has had links to or included open space planning, be it for 'green spaces' such as urban parks with largely unsealed, permeable surfaces consisting of grass, shrubs and trees, or 'grey spaces' such as plazas and squares with hard, impermeable surfaces (Swanwick, Dunnett, & Woolley, 2003). At a regional scale, planning and land management also includes landscape and resource protection (e.g., aquafers; minerals and agricultural land) and the structuring of urbanized areas through green belts and green wedges. Historically, there were recreational and aesthetic considerations (Olmsted, 1870, pp. 24–25) and environmental considerations guiding such work (Walmsley, 1995, p. 90). Ebenezer Howard's garden city and later movements promoting public parks for the health of urban populations attest that planners had a considerable awareness of the importance of open green space as a factor for quality of life.

The term GI was used first by Hauserman (1995) and Walmsley (1995) in the context of regional greenway network planning and urban neighbourhood scale greening concepts. In parallel, Ahern (1995)—a landscape architect—coined the term 'ecological infrastructure' emphasising the contribution of vegetated areas to ecological, hydrological and physical processes facilitating life. This connotation of GI promotes an ecosystem services lens to human wellbeing (MEA, 2005) and suggests a reframing of human-environment interactions (Chaudhary, McGregor, Houston, & Chettri, 2015) distinct from 19th and early 20th century values attached to green space. GI then gained further currency as evidenced by an increase in publications post turn of the Millennium (see Tzoulas et al., 2007). Publications on GI focus on a variety of aspects and are lodged in disciplines ranging from ecology and forestry to hydrology and environmental engineering and other built environment professions such as architecture, landscape architecture and planning. Additional fields such as sustainability science and public health are also entering the GI discourse. As different professions adopted the term, its meaning evolved (Mell, 2019) to encompass inter alia ecological as well as hydrological systems (green and blue space; cf. Liu, Chen, & Peng, 2014; Stovin, Jorgensen, & Clayden, 2008). Furthermore, from early on the emerging GI knowledge and practice was often linked to institutional understandings of planning systems as illustrated here for Sweden:

> It…seems necessary to upgrade urban space, preferably as a coherent planning entity [called] green infrastructure, and accord it the same status as other physical urban structure, e.g., buildings and highways. Only then would urban planners widen their attention to the manifold functions of urban green spaces. (Sandström, 2002, p. 380)

Overall, GI tends to refer to strategically planned and created regional-scale greenways or networks of connected green spaces. GI is to counter landscape fragmentation and the destruction of biotope/habitat functionality that often results from continued, unstructured settlement growth and urban sprawl. A key difference to standard open space or landscape planning is that GI moves beyond merely protecting and preserving natural areas (cf. Lennon et al., 2016); it entails the purposeful re-creation of multifunctional, open and green spaces and/or the improvement of the qualities of existing ones. This quality improvement of green spaces often emphasises the enhancement of the ecological, social, economic, and cultural values or so-called ecosystems services (e.g., Constanza et al., 2017; Daily, 1997) that such areas provide and which have been theorized elsewhere as 'fourth nature' contributing to developing regenerative natural habitats with rich biodiversity (Franzen, 2000; Landscape Architecture Association, n.d.; Sheppard, 2011). Green and open spaces, such as public parks which contribute to social cohesion and offer leisure opportunities can be conceived as a subset of GI, whereby GI is the overarching "term to describe the network of natural and semi-natural features within and between our towns and cities…rang[ing] in scale from street trees, green roofs and private gardens to parks, rivers and woodlands" (UK Green Building Council, 2015, p. 2). There is a clear notion that ecosystems approaches are required in urban settings (e.g., Chatzimentor, Apostolopoulou, & Mazaris, 2020) but, reconciling traditional land management perspectives with such ecological imperatives is a challenge for the planning profession which requires new working approaches and skills (Lennon et al., 2016).

An expanding list of studies on GI cover issues from finding a common definition, cost-benefit calculations of using green over grey infrastructure (e.g., Environmental Protection Agency, 2014) to exploring policy implications. There is considerable agreement that green infrastructure is multi-scalar and multifunctional. Connecting and re-connecting fragmented green spaces and corridors and ensuring that these spaces can contribute to a variety of different ecosystems services requires multiple actors to collaborate across sectoral and administrative boundaries (Hansmann et al., 2016; Lennon et al., 2016; Mayer et al., 2012). Moreover, it requires political support, funding, and scientific and technical knowledge as well as interdisciplinary and long-term thinking with a considerable need to coordinate activities of different professions and stakeholders. The need for a complex set of skills, knowledge and understanding around GI is now increasingly being acknowledged. Research identified limited skills and capacities to effectively and holistically assess the quality of green infrastructure (Calvert et al., 2018), to overcome silo mentalities and operationalise GI approaches on the ground (Lennon, et al., 2016) and a lack of understanding decision-making processes that may enhance GI via planning instruments and spatial policy (Cowell & Lennon, 2014). Mell (2019) and The Green Surge (2017) identified knowledge gaps in understanding geographical variability of GI effectiveness and stakeholder facilitation skills.

To conclude, GI planning is more complex than traditional 19th and 20th century green open space planning. A linear history of garden city planning via green belts to green infrastructure is certainly not obvious (Wright, 2011); rather GI planning is intrinsically linked to actively transforming cities and regions to 'greener' and less wasteful, regenerative places via smart, multifunctional design. The question arises, therefore: How can planners acquire the necessary competencies and skills to effectively instigate and steer GI planning? The next section investigates educational offers and whether these have kept pace with the conceptual developments, given that classical coverage of open space planning will unlikely do justice to the complexity associated with GI planning, policies, and implementation.

3. Educational Provisions for Green Infrastructure Knowledge Development

Professional knowledge and skills development for planning can be divided into 'initial' or formal education at university followed by continued professional development (e.g., Frank, 2020). This holds true for the majority of planners although increasingly different pathways into the profession emerge. The content of higher education curricula and those that typify land use and design are influenced by a mix of professional body and/or government guidance, practice demands, students, and academic research (Wiśniewska, 2011, p. 66). In an ideal setting, academic research, and professional practice feed off and influence each other (Calderhead, 1989). And, while accreditation guidance of major planning bodies tends to remain at more abstract and general levels (Akkreditierungsverbund für Studiengänge der Architektur und Planung, 2014; Planning Accreditation Board, 2017; Royal Town Planning Institute, 2015), the guidelines stipulate planning graduates acquire knowledge and skills in sustainable development. This in turn can serve as an implicit argument for the inclusion of GI skills and knowledge given the wide-ranging potential of GI to contribute to sustainability. Furthermore, given the government and professional body reports emphasising the importance of GI knowledge, one could expect that academics have begun to embed GI knowledge if not as programme specialisation, or free-standing modules then at least as a concept within relevant modules, e.g., on sustainable urban development. One also would expect continued professional development provision to cover the topic.

Assessing educational provision is notoriously difficult (Frank et al., 2014; UN Habitat, 2009). While at the continued professional development level, professional bodies' training calendars provide an overview, this may be complemented by a range of ad hoc events by independent providers that may accrue continued professional development credits but which are not listed in a way that can be interrogated easily. In higher education, programmes, modules, and their contents change regularly and there is no centralised database. Looking globally, issues around English translation, differing traditions and naming conventions inevitably mean that relevant provision remains hidden. Notwithstanding these constraints, we felt even a preliminary exploration of GI training and education provisions would be valuable. Data was collected with a three-pronged approach: (a) looking at continued professional development by canvassing the training offers of commercial providers and professional bodies for 2019/2020, (b) conducting Internet searches for higher education degree offers (credit-bearing certificates/Undergraduate/Postgraduate degrees), and (c) reviewing teaching provision (at module level) for GI at institutional level. Due to the exploratory nature of the study we do not claim to have captured education and training provision comprehensively. For example, for (a) and (c) we focused on the UK and North America—as researching such information requires a somewhat detailed understanding of professional body structures, traditions in terminology use and higher education systems. Other English language provision of continued professional development or in higher education programmes in Northern Ireland, Australia/New Zealand, in Scandinavia or the Netherlands are therefore largely not captured in this study. For (b) a global Internet search was used and to retain the focus of the study a clearly defined set of terms was used (see Table 1). It is acknowledged that results are very likely underreporting activities.

3.1. GI in Continued Professional Development Provision

In the UK, opportunities on green infrastructure training for planners tend to be covered as part of green belt planning, residential development and planning for climate change mitigation and adaptation, and flood management via short webinars, full and half-day seminars as indicated by the Royal Town Planning Institute's, the Town and Country Planning Association's, or the Landscape Institute's published calendars (on average 1–2 events/month). Similar training events exist for planners in the US through the Environmental Protection Agency and the American Planning Association (n.d.), although there is perhaps a greater focus on water management issues. A report (Emmett Environmental Law & Policy Clinic and the Environmental Policy Initiative, 2014, p. 15) examining professional certification options for GI professionals across the US revealed a high level of specialisation both geographically (single state or county) and technologically (e.g., rainwater harvesting, or storm water inspection and management) leading the authors to call for governments to drive development of GI standards and deployment of GI through regulatory tools and potentially run certification programmes (Emmett Environmental Law & Policy Clinic and the Environmental Policy Initiative, 2014, p. 28). In Canada, the Gaia College and Royal Roads University offer a 12-week course on Living Green Infrastructure geared toward:

> Planners, policy makers and developers to provide knowledge and tools to assist professionals and practitioners in attaining a proficient level of competence in living green infrastructure, and for implementing these technologies and best management practices throughout the planning, constructing and maintenance phase of land development. (Royal Roads University, n.d.)

The course is approved for continued professional development credits for a range of landscape professionals to maintain certifications and contributes to the Advanced Diploma in Organic Land Care awarded by the Gaia College (Gaia College, n.d.). It should be noted that other association such as, for example, the Forestry commission, or civil engineering societies or nature conservation groups also might provide continued professional development. It is worth noting, though, that a professional requirement for continued professional development credits might reinforce professional silos and limit practical choices of where training is sought.

3.2. GI in Initial Spatial Planning Education

Looking at Bachelor or Master programmes with a focus or specialisation in green infrastructure, a Google search for "'degree program*' AND 'green infrastructure'" was conducted (13 December 2019) in English, whereby the asterisk functioned as wild card to include variations of the relevant word. This unearthed relatively few results (Table 1). One degree with a specialisation and a certificate each were found in Europe, Australia, and the UK, and three in the US. While the table shows all results from the focussed search, this is likely a considerable undercount. It is interesting that two of the Masters, the MSc at the Erasmus University (the Netherlands) and the Master of Biological and Agricultural Engineering (North Carolina State University) adopt a rather technical interpretation of GI. This emphasises the diversity of GI interpretations, an assimilation of the concepts into different professional realms and in turn a need for better transdisciplinary understanding. The widespread absence of 'GI' in programme titles can be interpreted in at least two

Table 1. Higher education degrees/certificates focusing on GI education.

Programme name	Institution	Unique selling point
Certificate in Green Infrastructure	University of Melbourne, Australia	"The Graduate Certificate in Green Infrastructure…will teach you how to use vegetation to improve urban environments for their residents" (University of Melbourne, 2020).
Master of Biological and Agricultural Engineering	North Carolina State University, NC	"Interested in low impact design? Go green and use your science and math skills for the greater good. Build a career in green infrastructure" (North Carolina State University, 2020).
Sustainable Environmental Systems MSc	Pratt Institute, NY	"Pratt's Sustainable Environmental Systems program offers a studio in which students gain skills to design green infrastructure in a variety of settings" (Pratt Institute, 2020).
MSc Infrastructure and Green Cities	Erasmus University, Rotterdam, the Netherlands	The Infrastructure and Green Cities programme is a specialisation track within the MSc in Urban Management and Development. Key topics include green transport and infrastructure (including drainage).
Urban Planning MSc with Green infrastructure and Landscape planning pathway	Newcastle University, UK	Green Infrastructure (GI) is the development of solutions to address the increasing human impact on the environment. GI…can enhance, restore or create landscapes with spaces and linkages for both human and natural systems. You will gain an understanding of: a) the legal framework of GI and b) engagement with local communities.
Master of Urban and Regional Planning	University of Colorado at Denver, CO	One focus/specialism explores issues like air quality, water supply, habitat fragmentation, green infrastructure, parks, energy consumption, and transportation equity.

ways: GI might be seen still as something very narrow and specialist and thus unlikely to attract large student numbers, or GI is conceived as an integral part of another built environment or engineering profession therefore only to be covered in shared or optional provisions and pathways.

3.3. GI Provision as Part of Spatial Planning Programmes

Gaining insight into subprogramme level content is challenging as within a programme, module content can and is often updated without changing the module title to avoid administrative work. In some cases, planning educators even have been dissuaded from using GI in module titles by their departments as the term 'infrastructure' could be (wrongly) associated with engineering works which were deemed inappropriate in a planning education context (Greve, 2017).

For this aspect of the study, different methods traditionally used to gain insights into teaching content were employed. For example, we examined accreditation documentation where accessible and surveyed instructors including soliciting syllabus and reading lists. These methods will generally provide accurate information and detail. However, the effectiveness of these method relies on trust and works best if targeted directly to relevant scholars or if managed via an umbrella organization towards which there is a feeling of responsibility (e.g., accrediting body) in a narrow and well-defined field. GI knowledge, however, is interdisciplinary and there are in theory, at least, many different disciplines in universities that could be covering GI topics and which students of planning could access. To gain a more comprehensive overview of GI teaching, therefore, a wider range of departments would need to be surveyed. Here a curriculum assessment tool, which uses a computerised analysis of key words/phrases in module titles and descriptions (e.g., Lozano & Peattie, 2011) could be employed. Such an approach offers efficiencies across a larger set of disciplines but requires access to a searchable database of module descriptions. For ambiguous, and broad concepts with different interpretations, the method might lead to less robust results than a targeted survey.

As access to a 2017 module database was granted at Cardiff University, this approach was used searching of all module titles and descriptions from the departments of Architecture, Geography and Planning, Biosciences, Business School, Social Sciences, Engineering, and Earth Sciences using Boolean search combinations of two and three terms. The results were quite meagre (Table 2) with only two modules in Architecture showing matches for two keywords and 15 matches for two keywords in Geography and Planning and two modules with a match for all three terms. All other departments only showed results for single keywords. Selected follow-up interviews and reflections by instructors of identified modules led to a better understanding of the meaning attributed to GI, and how much of the teaching was focused on GI and what aspects might be covered (e.g., design aspects, or policy). This revealed first that lacking a clear strategic steer or need, through accreditation requirements, individuals had little incentive to make major changes in module content. Secondly, it revealed a wide range of interpretations with one lecturer (L1) defining GI as the necessary infrastructure to enable and support alternative 'green' modes of transportation such as walking or cycling, and another relating it to water management issues and "infrastructure of [the] built and ecological environment" (L3).

Using more standard survey methods (via Internet searches and interviewing scholars) looking at spatial/urban/regional planning degrees programmes in the UK, we found the following modules at Undergraduate or Postgraduate level with explicit titles incorporating GI: at the University of Manchester students of the BSc Planning and Environmental Management have access to a module on Green Infrastructure and Sustainable Cities, likewise the University of Liverpool offers an optional module on Green Infrastructure Planning for planning related degrees (BA in Geography and Planning/Urban Planning and integrated MA in Urban Planning). At the University of Sheffield, a module on Health, Wellbeing and the Built Environment includes contributions of GI to well-being. Other UK institutions offering Royal Town Planning Institute accredited planning degrees do offer as part of undergraduate and MAs degrees, modules on sustainable and healthy cities and it is fair to assume that GI will be touched upon but it is not clear what proportion of the module time will be dedicated to GI design, governance, and implementation or policy and what scales are being looked at. At University College London the UG planning programme has a required module on Green Futures which will cover also green infrastructure, however interestingly, their MA in Sustainable Urbanism does not list any module titles containing green infrastructure. In contrast, at Kingston University, the Landscape and Urbanism MA covers not only Green and Blue Infrastructures but also associat-

Table 2. 2017 Module catalogue key word search results at Cardiff University.

Keywords	Architecture	Geography & Planning
Green + Urban	2	15
Green + Infrastructure	0	2
Urban + Infrastructure	0	2
Green + Urban + Infrastructure	0	2

ed topics of "wellbeing…climate change, biodiversity" (Kingston University, 2020).

Among US-based planning programmes, the inclusion of GI courses or a component of a course dealing with broader subject matters are similarly limited. Provision seems most prevalent when there is a joint relationship between landscape architecture and planning. For instance, the University of Massachusetts, Amherst includes these two disciplines in the Department of Landscape Architecture and Planning. A jointly offered course, LA/RP 582 Landscape and Green Urbanism: Theory and Practice, links together GI, sustainability and resilience within the broader frame of green urbanism. At the University of Virginia, a course entitled Green Cities/Green Sites, and Green Lands explores the implementation of GI at different scales in Virginia communities. The course "assesses the existing 'green infrastructure' of counties in Virginia and…students will use the existing county comprehensive plan to create effective strategies for implementation of goals related to conserving open space and creating livable communities" (Firehock, 2007, p. 13). At the University of Florida, a course on Environmental Land Use Planning and Management requires students to assess local plans for their level of ecological integrity and how they embrace green infrastructure approaches (URP 6421 Syllabus 2019). The landscape architecture programme in Harvard University's Graduate School of Design, offers a course, Green Infrastructure in the Non-Formal City, that incorporates perspectives on strategies to manage sewerage, stormwater, potable water, waste and energy in extra-legal settlements, particularly in the global South while in the University of California Los Angeles Department of Urban Planning, a course entitled Green Urbanism: The Building Blocks for Creating Sustainable Places examines GI drawing extensively upon Los Angeles and other California experiences in advancing sustainability through green interventions. By contrast, courses in green infrastructure in the Department of Urban Planning at Texas A&M, focus on GI and human health at the intersection of planning and design. This is accomplished by incorporating an ecological approach in existing offerings, such as an interdisciplinary course, Planning Healthy Communities, which show how GI is an integral part of the relationship of health, planning and design and how the dynamics of this relationship shapes our communities. Jane Futrell Winslow (personal communication, December 29, 2019) stated that there has been also a proposal for a standalone GI course, Green Cities, Healthy Cities, which would offer an even more intensive coverage of the topic. In the University of Pennsylvania's city and regional planning programme, two courses incorporate GI, one being Sustainability and Environmental Planning, and the other, Preserving Agricultural Land (T. Daniels, personal communication, December 30, 2019). Both draw upon the instructor's own research in green infrastructure but also expose students to the growing literature in the field.

4. Discussion

The review of education opportunities for spatial planners regarding GI knowledge and skills reveals a mixed and changing picture. A Google search of "'green infrastructure' AND 'planning education"' shows a growth in hits from 15,900 (August 6, 2017, 12:30am UK time) to 37,900 (July 24, 2020, 17:30 UK time). "'Green infrastructure' AND 'urban planning program*"' and "'green infrastructure' AND 'urban planning course"' resulted in 9,430 (2017) and 22,300 (2020) and 1,530 (2017) and 2,750 (2020) hits respectively. The term "'green infrastructure' AND 'planning education curricul*"' yielded merely 2 results on November 22, 2017, but 2,400 on July 24, 2020. This suggests that GI education options are increasingly provided and written about as part of planning but also of other disciplines. While GI is seen as multifunctional, education and research appears to be centred around thematic clusters such as biodiversity, ecosystems services or green spaces/corridors and forests at the municipal level (e.g., Chatzimentor et al., 2020) at least in the European context. Table 1 corroborates that GI is embraced by a range of professions and disciplines in higher education.

Opportunities for continued professional development as well as a set of programmes in higher education exist that are geared to enhance GI skills and knowledge. Given an identified need to bolster interdisciplinary working when operationalising a GI approach, the effectiveness of practice sessions by a single professional body may be limited. Other, interactive approaches such as those proposed by The Green Surge (2017), or Lennon et al. (2016) featuring gaming and interactive workshops that offer nonthreatening learning environments for interdisciplinary professional groups may have deeper impacts. Both examples derive from research projects. Instincts to protect professional boundaries and turf will likely prevent traditional professional associations and societies—be it urban planners, landscape architects or engineers—from offering such activities in their standard continued professional development programmes.

Reviewing results for planning education in higher education suggest that individual scholars championing the topic as well as a linkage between planning and landscape architecture that characterizes some US programmes, or environmental sciences (in the UK) are likely factors supporting current offerings. Nevertheless, GI is (still) not what might be considered a 'core' competency in planning education in either country despite an ever more urgent demand for GI integration in urban space. With few exceptions GI is only an optional topic amongst others in planning education related to environmental issues. This is a precarious situation as is illustrated by the Green Infrastructure Design-Built Studio at the Pratt Institute in New York City. The studio ran every summer from 2012 to 2016 as part of the MS Sustainable Environmental Systems but has ceased probably due to a change in instructors or because on campus built-design opportunities have dried up.

Green infrastructure can be viewed as one dimension of a wider gamut of measures that support planning and policy for sustainable urban land management (Hansen et al., 2017) which typically is included in most accreditation criteria for urban, regional or spatial planning degrees (e.g., Planning Accreditation Board, 2017; Royal Town Planning Institute, 2015). As a result, students are exposed to concepts that support sustainable development such as walkability, mixed-use zoning, as well as aspects of green infrastructure. As time on degree programmes is limited, programme leaders are careful not to introduce a new module or speciality each time a seemingly relevant topic appears. In our own position as researchers on GI and educators we have reflected upon how GI might be incorporated into planning education and recognized limits on our ability to innovate that arises from real and perceived constraints including: (a) teaching on 'core' modules with prescribed learning outcomes by the accreditation body curbing the flexibility to introduce new content; (b) managing curriculum time: with a fixed amount of credits difficult decisions arise on what is essential to retain and what might reasonably be replaced. The challenge of refreshing module content can be exacerbated in team teaching situations when colleagues insist on retaining their contribution; (c) managing workload when it can (most likely is) more straightforward to update existing material rather than replace it with new material; and (d) catering to student expectations; if a module is well received it is tempting to be risk averse and reproduce it rather than introduce change.

Scholar-driven teaching innovations on GI, therefore, are likely to remain small-scale, ad hoc and often hidden from the gaze of others, including the host institution as many of the examples demonstrate where GI is part of the teaching or used in assignments but the module title does not indicate any GI content specifically. Dynamics could be changed via external pressures from relevant stakeholders such as practitioners or accreditation requirements—entities that tend to play a role in shaping education content through curriculum reviews and audits. Private sector interests in the planning realm are important for GI in two ways: On the one side they can provide guest lectures, and continued professional development and on the other they make knowledge demands about the types of training that they think are valuable for professional planners. In an increasingly neoliberal education system course content is often judged whether it is fit for purpose by recourse to standards and measures. Employability statistics are highly valued by those who seek to promote courses and distinguish them from competitors. More reflective or challenging perspectives on planning that are valued in academia may be less valued by the planning community. GI seems to fall between the two stools: there is not an obvious market demand for planners to be trained in GI—although this may be changing given the recent calls for more quality open space in urbanized areas (Royal Town Planning Institute, 2020) or critique of failures to operationalize GI approaches effectively (Cowell & Lennon, 2014; Lennon et al., 2016; Meerow & Newell, 2017)—nor does GI with its links to practice readily offer itself for theoretical critique. Wiśniewska (2011) suggested that some topics are unlikely driven by the profession or the market and it may fall to governments and academics to lead on inserting challenging and critical elements into curricula so as to ensure that students are introduced to progressive new knowledge areas and concepts.

We know from experience that innovations also have unintended side effects and as such it is vitally important to scrutinize them thoroughly. Planners need a solid grounding of what is GI, its principles, benefits, drawbacks, its planning, design, implementation, and management/maintenance. And while continued professional development opportunities exist, we feel an earlier exposure of future planners to the subject would assist the imperative ecological shift promoted by so many professions. Thus, at a minimum planning education should cover basic theoretical debates as well as practical issues via a lecture course and studio on, for example, place development or strategic planning. Additionally, curricula should include options, ideally in collaboration with other disciplines and departments emphasizing the need to work across disciplinary boundaries to build on synergies and other knowledges. Provision of such modules are increasingly emerging in university course catalogues; they include topics such as: (a) green infrastructure in Non-Formal Cities (development studies/politics); (b) green infrastructure and water management (with engineering); (c) green infrastructure and health (with public health/medical sciences); (d) urban food production and sustainability/circular economy (economy/engineering); (e) green infrastructure and biodiversity (with Biology); (f) green infrastructure for recreation (with sports/recreation studies); and (g) green infrastructure and buildings (with architecture).

5. Summary and Recommendations

Four decades from first introducing the concept of GI in spatial planning literature (e.g., Hauserman, 1995; Walmsley, 1995), a proliferation of reports and guidance on the subject have soundly established a central role for GI in planning for sustainable cities and regions (e.g., American Planning Association, 2007; Environmental Protection Agency, 2014; Royal Town Planning Institute, 2013; UN Habitat, 2017). The 2020 health pandemic caused by Covid-19 has, if anything, corroborated the value and necessity of planning and implementing GI and quality open spaces in cities for the health and well-being of inhabitants (Royal Town Planning Institute, 2020).

Considering this, our aim was to explore what types of GI knowledge planners may require and by whom and how this knowledge may be provided and disseminated.

And, while Wiśniewska (2011) amongst others alluded that the development of GI and its link to sustainability and health appears in part to be a re-packaging of previously used concepts of green open spaces and multifunctionality in planning to fit with the rhetoric of sustainable development, scholars also suggested that GI is far more complex (Lennon et al., 2016) than traditional green space planning and requires particular skill sets for its successful implementation including interdisciplinary working, enacting multi-institutional governance and multidisciplinary stakeholder facilitation.

Preliminary explorations into the provision of GI knowledge and skills within higher education planning degree courses indicate that the concept's varied interpretation combined with abstract accreditation guidelines and conflictual value systems and perceptions undermine more explicit and systematic coverage of GI issues, particularly, in terms of policy and theoretical foundations. It may be astounding that teaching and learning of and about GI seems not to have gained a more prominent role in planning curricula to date. Yet, given Nasr and Komisar's (2012) findings that integration of an interdisciplinary field into design and planning education (referring to food planning) is challenging, it should not come as a surprise that GI has not been able to establish itself more firmly as a core planning theme.

Continued professional development courses are offered covering mostly practical issues of plan implementation in short 1h to 1-day long sessions which are unlikely to address GI critically or to promote interdisciplinary GI thinking. While research has explored impactful training in this area using gaming and interactive interdisciplinary workshops, additional work is needed to explore how such activities could be made attractive across the diverse professions and disciplines involved in GI implementation.

Given the growing urgency to reconsider the human-nature relationship, it is vital that built environment professionals gain comprehensive skills and understanding of GI planning issues. The fragmented and ad hoc provision at present will not suffice; instead, a ramping up of capacity building activities across a range of disciplines including spatial and urban planning is needed. A thorough introduction of the link between GI concepts and planning at initial education stages would be in our opinion advantageous to offer a grounding for future planning professionals. This could effectively complement and bolster efforts to upskill and train planning practitioners in GI thinking through continued professional development.

While Wiśniewska (2011) suggested that practice may not keen to embrace and therefore push novel concepts for inclusion in education, the possibility, importance and success of government intervention in shaping educational agendas has been highlighted by Emmett Environmental Law & Policy Clinic and the Environmental Policy Initiative (2014). As such more formal inclusion of GI issues in the planning curriculum might best be supported by requirements from accrediting bodies but may also require concerted action from academia in terms of bolder integration of GI research in teaching. The increasing rhetoric by politicians, and city makers around biophilic cities and bringing nature back into the built environment should help make a case to integrate GI into planning programmes. To promote this agenda, it is suggested that planning educators: (a) investigate on a national or continental basis GI skills and knowledge needs; (b) lobby professional bodies, governments and agencies to include GI in accreditation guidance; (c) create interdisciplinary communities of practice to exchange experiences in course design and delivery; (d) collaborate with researchers that conduct research on GI, including developing interdisciplinary frameworks and theoretical aspects; and (e) create specialisation streams/certificates in GI to embed the topic as core planning theme alongside other progressive ones such as climate change and strengthen links to other fields such as health/biology/engineering.

Acknowledgments

The authors are grateful for a 2-month Cardiff University Research Opportunity Placement for Joanna Pogorzelska who provided data collection and research support.

Conflict of Interests

The authors declare no conflict of interests.

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Urban Planning (ISSN: 2183–7635)
2021, Volume 6, Issue 1, Pages 75–88
DOI: 10.17645/up.v6i1.3633

Article

Green Infrastructure and Biophilic Urbanism as Tools for Integrating Resource Efficient and Ecological Cities

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Submitted: 7 September 2020 | Accepted: 30 November 2020 | Published: 26 January 2021

Abstract
In recent decades, the concept of resource efficient cities has emerged as an urban planning paradigm that seeks to achieve sustainable urban environments. This focus is upon compact urban environments that optimise energy, water and waste systems to create cities that help solve climate change and other resource-based sustainability issues. In parallel, there has been a long-standing tradition of ecological approaches to the design of cities that can be traced from Howard, Geddes, McHarg and Lyle. Rather than resource efficiency, the ecological approach has focused upon the retention and repair of natural landscape features and the creation of green infrastructure (GI) to manage urban water, soil and plants in a more ecologically sensitive way. There is some conflict with the resource efficient cities and ecological cities paradigms, as one is pro-density, while the other is anti-density. This article focusses upon how to integrate the two paradigms through new biophilic urbanism (BU) tools that allow the integration of nature into dense urban areas, to supplement more traditional GI tools in less dense areas. We suggest that the theory of urban fabrics can aid with regard to which tools to use where, for the integration of GI and BU into different parts of the city to achieve *both* resource efficient and ecological outcomes, that optimise energy water and waste systems, *and* increase urban nature.

Keywords
biophilic urbanism; ecological cities; green infrastructure; resource efficient cities; urban fabric theory; urban planning

Issue
This article is part of the issue "Urban Planning and Green Infrastructure" edited by Paul Osmond (University of New South Wales, Australia) and Sara Wilkinson (University of Technology Sydney, Australia).

1. Introduction

The numerous benefits of urban nature, such as ecosystem services (e.g., urban cooling, flood mitigation), increased biodiversity, health and economic benefits are well established in the literature (Brink et al., 2016; Hansen et al., 2015; Mcdonald, Beatley, & Elmqvist, 2018; MEA, 2005). However, many urban dwellers do not live close enough to urban nature to receive these benefits (Mcdonald et al., 2018), the challenge remains where and how to (re)integrate nature into cities, especially in large and densely developed cities where little space can be found. In dense urban areas where undeveloped land can be found, justifying its preservation for urban nature may be difficult to argue because pressure is high for other uses, e.g., affordable housing, parking or local job creation through commercial buildings. This is made harder when the global and local agenda for dealing with major issues like climate change is seen to need increases in density, not decreases (Intergovernmental Panel on Climate Change [IPCC], 2018; Newman, Beatley, & Boyer, 2017; United Nations, 2017). Limited urban space has traditionally meant reduced integration of ecosystem services. Similarly, despite considerable literature extolling the benefits of ecosystem services, uptake in urban planning discourses and practice is slow, highlighting the need for systemic approaches for integrating urban nature within urban planning (Hansen et al., 2015). So, how can the urban planner address the need to increase urban nature in cities while also addressing the need for dense urbanism?

This article describes how there are new tools that can help with this resolution. It suggests that we need to begin by recognising that there are two major urban planning paradigms for how cities must face the 21st century—ecological cities and resource efficient cities—and if they are not understood as both having legitimacy in urban planning, then it will be difficult to resolve some of their inherent conflicts. The article suggests that there is a fundamental issue about urban density that leads to their conflict. It seeks to resolve this conflict and show how ecological cities and resource efficient cities can be better integrated to create more complete solutions to 21st century urban problems through the adoption of the two tools of green infrastructure (GI) and biophilic urbanism (BU). Thus, it is an early attempt to help resolve the conflict that arises between the need for density to optimise circular urban systems within resource efficient cities, and the need to find space to maximise urban nature in ecological cities.

The article aims to show how the theory of urban fabrics (Newman, Kosonen, & Kenworthy, 2016) can offer a useful lens to assist urban planners and policy makers when considering how, and where, to integrate urban nature into different parts of the city using the two tools. The approach involved reviewing current and classic literature on ecological cities and resource efficient cities. Subsequently, the theory of urban fabrics was used to begin to develop a typological categorisation for integrating nature into urban areas based upon urban morphology and density. The key is to begin by recognising that there are different urban fabrics within a city, therefore rather than having a simple manual for urban nature integration across a whole city, an urban fabric typology will allow for a nuanced response to urban nature integration into different parts of a city. This article represents a first step to integrate several concepts in the hope to show that planners should not only consider urban nature within designated open space, gardens or residual land, but that the possibility also exists to retrofit urban nature into established and dense urban areas.

1.1. Paradigm 1: Ecological Cities

There exists a long history of proponents for the integration of nature into cities, below we introduce several notable names, including Howard, Geddes, McHarg and Lyle who helped establish the paradigm of ecological cities.

A little over 100 years ago Ebenezer Howard's concept of the 'garden city' became highly celebrated as a city planning concept. At its essence it takes the best elements of town, and country, in a new typology town-country. Town-country blends the beauty of nature with the social opportunity of the city, at least that was the promise. Howard outlined his vision for the ideal garden city as a highly prescriptive modular, symmetrical urban structure of separated land uses that should house 32,000 people across 9,000 acres (Howard, 1902). Despite being hugely popular the ideal plan was never fully realised at the city-scale, rather it inspired many smaller subdivisions in the UK and around the world, as neatly designed subdivisions with housing, local shops, geometric street patterns and abundant urban greenery. Equally relevant as the planning principles of the garden city movement, are those socio-technical drivers that led to its popularity. Howard's ideas were born in the Victorian era. The timing is significant, as this was a period where uncontrolled coal burning to fuel industry and warm households led to blackened skies in and around urban areas, creating the 'smoke fiend' (Howard, 1902). Howard's vision was for smokeless cities, that combined the benefits of urban life and work with the access to nature found in the countryside. The vision of low density green suburbs was born in this era (Kostoff, 1991; Mumford, 1961).

Patrick Geddes was a contemporary of Howard, who took a more scientific approach to the incorporation of nature into cities. In the late 19th century and early 20th century he described the intersection between the human systems of town planning and the natural systems of ecology and geomorphology. Geddes lamented that the loss of "natural conditions" and those "great open spaces…[the] lungs of life, are already all but irrecoverable" (Geddes, 1915, p. 34). Geddes work was highly influential upon Ian McHarg, the landscape architect who in 1969 wrote the influential publication *Design with Nature*, in which he outlines an ecological view to accommodate natural conditions in areas of urban expansion. McHarg's 'sieve mapping' approach starts by identifying the most valuable landscape elements as a 'landscape footprint,' i.e., an area to be preserved; with the residual low ecological value areas designated as the 'urban footprint,' i.e., an area to be developed (McHarg, 1969). McHarg, was not known for his love of cities, but he outlined a systematic approach to preserve those 'irrecoverable' spaces, as Geddes called them, from urban displacement. In the 1980s and 1990s another landscape architect, John Lyle, drawing upon environmental elements of nature restoration, developed the notion of 'regenerative design' (Lyle, 1996). Lyle's approach went further than McHarg's conservation of landscape footprint, seeking instead to regenerate the ecological function of degraded landscapes. Lyle's work was largely landscape based, but regenerative design is increasingly applied to the restoration of degraded urban areas (Girardet, 2010, 2015; Mang & Reed, 2012). Geddes lamented the loss of access to nature, but McHarg and Lyle show how it is possible to preserve and regenerate ecological functions in urban areas. Collectively the works of these early thought leaders set the conceptual groundwork for the current proliferation of writing about nature in the city.

Cities are designed landscapes and human settlements are typically sited in response to natural conditions i.e., bioregional context, topography, hydrology, soils and so on, but as the city grows the artificial subsumes the natural. In many of the world's larger cities scant evidence of these original natural conditions remains. A consequence has been the general decline in urban dwellers' everyday interaction with nature, as well as loss of the many ecological functions of those natural features. This trend has been observed across the globe (Soga & Gaston, 2016), in response, some authors have highlighted the need to re-connect urban dwellers with nature (Andersson et al., 2014; Samuelsson, Colding, & Barthel, 2019). Scientists have been calling for some time for the urban narrative to change away from the perception of city-nature duality towards a greater integration of nature (Grimm et al., 2008; MEA, 2005). Increasingly city and regional planners are also recognising that better integration of natural systems is necessary (Newman & Jennings, 2008). However, to create space for nature, cities should necessarily spread out. Inspired by Raymond Unwin's (1912) garden cities pamphlet, the early motto of the Town and Country Planning Association was "nothing gained by overcrowding." But how is this done when the other major paradigm, resource efficient cities, appears to be working against this by promoting density?

1.2. Paradigm 2: Resource Efficient Cities

From the 1940s on, suburbs based around automobile dependence absorbed huge amounts of land as they rolled across the landscape leaving little of the natural features behind. The first studies on sustainability in cities showed that the low-density car-based suburbs were extremely high in resource consumption (Newman & Kenworthy, 1989, 1999). This moved into an era of urban planning to try and reduce car dependence through increased density, particularly around transit systems, to reduce travel demand (Calthorpe, 2010).

'Urban regeneration' is a process that the modern planning profession has used for well over three quarters of a century—typically to reverse the physical and social decline of an urban precinct via redevelopment (Roberts, Sykes, & Granger, 2016); but increasingly there is an ecological component to regeneration, with a planning intent to create a significantly smaller ecological footprint as well as higher amenity through more equitable access to urban jobs and services (Newton & Thomson, 2016; Rees & Wackernagel, 2008).

At its essence, resource efficient cities is a process whereby urban areas are designed to reduce adverse environmental impact between the city and the ecosystems from which it draws its resources (Girardet, 2010, 2015; Hes & du Plessis, 2014). Delivering resource efficient cities is an integrated process involving energy, water, waste within any urban area, but has mostly focussed on how it can make cities into being more regenerative of the atmosphere as climate issues have become a bigger and bigger focus (Thomson & Newman, 2016, 2018a). Thus, the resource efficient city paradigm aims to achieve more than conventional city planning driven by real estate markets or occasionally social renewal.

But significant research in the past 50 years indicates that resource efficiency potential is greatest in compact cities (Creutzig et al., 2018; Neuman, 2005); this view is supported by the IPCC's assessment of cities and their policies to help shape a decarbonised future (IPCC, 2018; Seto et al., 2014). Thus, the notion of higher density to enhance resource efficient outcomes may in fact be in conflict with major elements of the low-density agenda within the ecological cities paradigm.

2. The Clash Between the Two Paradigms

Both the ecological and resource efficient urban planning paradigms have legitimate claims to being powerful guidance systems for planning the cities of the future. Resource efficient cities seek to create dense centres of development that can create more renewable energy than consumed, as well as other environmental improvements, i.e., they are compact. Compact cities also minimise encroachment on ecologically or agriculturally important land on city fringes (Folke, Jansson, Larsson, & Costanza, 1997). However, compact city and urban infill agendas have their own limitations, and a long standing criticism of dense cities has seen the disappearance of gardens, reduced urban ecology and other ecosystem services within cities as a result of urban intensification (Breheny, 1997). The pressure to regenerate cities means that redevelopment can indeed conflict with ecological outcomes.

When some planners want to see increased urban density in areas to improve the sustainability and resource efficiency potential of a city (Newman & Kenworthy, 1999), other planners object on the basis of ecological disturbance and loss of ecological functions (Lo, 2016). The next section describes how urban planning can possibly reconcile this apparent conflict using some new tools that are increasingly available to cities around the world.

3. Tools for Integrating the Planning of Ecological Cities and Resource Efficient Cities

Two tools will be outlined that can help planners integrate both the ecological and the resource efficiency approach within cities: GI and BU.

3.1. Green Infrastructure (GI)

GI can be considered a counterpoint to the 'grey infrastructure' of roads, buildings, car parks and other impervious hardscapes that typify industrial cities of the Modern era. GI can be defined as a:

> Strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life. (European Commission, 2013, p. 3)

3.2. Biophilia and Biophilic Urbanism (BU)

Biophilia was defined by Wilson (1984, p. 1) as "the innate tendency to focus on life and lifelike processes." Wilson was an ecologist whose special insight was that this biophilic propensity developed as part of evolutionary survival, so it remains with humans in their daily lives, even in modern cities (Newman, 2020). Biophilic design has become a major social movement within city policy and practice (Beatley, 2011; Kellert, 2012). There is now a Biophilic Cities Network with membership across the globe as they work together showing how cities can integrate nature. This inevitably involves town planning and previous studies describe biophilic city design elements across scales, from building, block, street, neighbourhood, community, and region (Beatley & Newman, 2013).

BU has developed a series of science and engineering approaches that mimic natural systems within denser urban environments. These emerging BU approaches mean urban greenery is no longer limited to undeveloped land, but can also be integrated on, in and over built structures, for example as integrated green walls and green roofs as biophilic facades on buildings (Figure 1). Similarly, integrated water management approaches allow for local infiltration, rather than traditional grey infrastructure approaches that channel or pipe water away from urban areas and into remote detention ponds, rivers or the sea (see Beatley, 2011).

BU has been increasingly applied to the densest parts of cities with some success such as in Singapore (Newman, 2014). While the planning concepts of compact resource efficient cities versus spreading ecological cities appear to clash, they can be reconciled through GI integration in dense urban areas using BU approaches. BU provides new opportunities for urban ecology to become a crucial element of the resource efficient cities approach. GI/BU has the potential to deliver a range of cross cutting benefits such as food production, clean water and air, reduced storm water flows, urban cooling (Pauleit, Zölch, Hansen, Randrup, & Konijnendijk van den Bosch, 2017), just as the ecological cities paradigm has always suggested but it can now be done in dense areas as well as low density areas.

Section 4 describes how urban planning can potentially resolve the two paradigms through integration, by utilising the spatial characteristics of different urban fabrics, i.e., by facilitating traditional GI approaches in less dense urban fabrics, and BU approaches in denser urban fabrics.

Figure 1. 'Central Park' Sydney, Australia: Biophilic façade. Source: Katherine Lu.

4. The Theory of Urban Fabrics: Integrating Resource Efficient and Ecological Cities

4.1. Theory of Urban Fabrics

Urban fabrics are products of transport-related lifestyles and functions that have needed certain physical elements and environments to enable them (Newman & Kenworthy, 2015; Newman et al., 2016). Each urban fabric has a particular set of spatial relationships (Figure 2), building typologies and specific land-use patterns that are based on their transport infrastructure priorities.

All cities are made from a mix of urban fabrics each with different characteristics, including different opportunities or limitations for the incorporation of natural systems using GI and BU. Recognising this allows for a more nuanced planning policy response that can potentially resolve the conflict between the two planning paradigms. This holds true for new urban development and perhaps more critically, for urban retrofits. The four dominant urban fabrics roughly correspond to major socio-technical stages in industrial society that are reflected in urban form and which continue to be regenerated in each new period of history (Newman, 2020).

4.1.1. Walking Urban Fabric

Prior to the 1850s nearly all cities were walking cities, characterised by dense, mixed-use areas of generally more than 100 persons per hectare. These are the oldest typology, this fabric dominated until the 1850s. Many modern cities, are built around a nucleus of an older walking city, but they struggle to retain the walking urban fabric due to the competing urban fabrics especially automobile city fabric which now overlaps it, but there is a global movement to introduce more, or regenerate old walking urban fabric (Gehl, 2010; Matan & Newman, 2016; Newman & Kenworthy, 2015). The high density of walking urban fabric means that there is usually little space available for traditional GI outside of formal open space or parklands.

4.1.2. Transit Urban Fabric

Between 1850 and 1950, trains, followed by trams from the 1890s, extended the old walking city. This transit urban fabric takes the form of corridor development with typical densities between 35 and 100 persons per hectare, yet higher density walking fabric still remained around transit stops. The increased speed of transit allowed development to extend 20 km or more from the centre. There is a growing push for sustainable cities to reinstate or introduce, dense transit corridors to move large volumes of people and alleviate congestion, this is particularly advanced in Asian cities (Gao, Newman, & Webster, 2015). Density remains high in transit urban fabric, but the slightly lower densities mean it is usually less constrained in terms of GI opportunity than walking urban fabric.

4.1.3. Automobile Urban Fabric

From the 1940s onward, western cities, and increasingly the world's cities, have been dominated by low-density automobile urban fabric. The term 'automobile dependence' was developed in the 1980s to express how cities were increasingly being built around the car (Newman & Kenworthy, 1989). Automobile fabric is composed of low-density suburbs (population densities of less than 35 persons per hectare), due to the flexibility and speed (average 50–80 km/hr on uncongested roads) of automobiles to spread over considerable land area. Automobiles

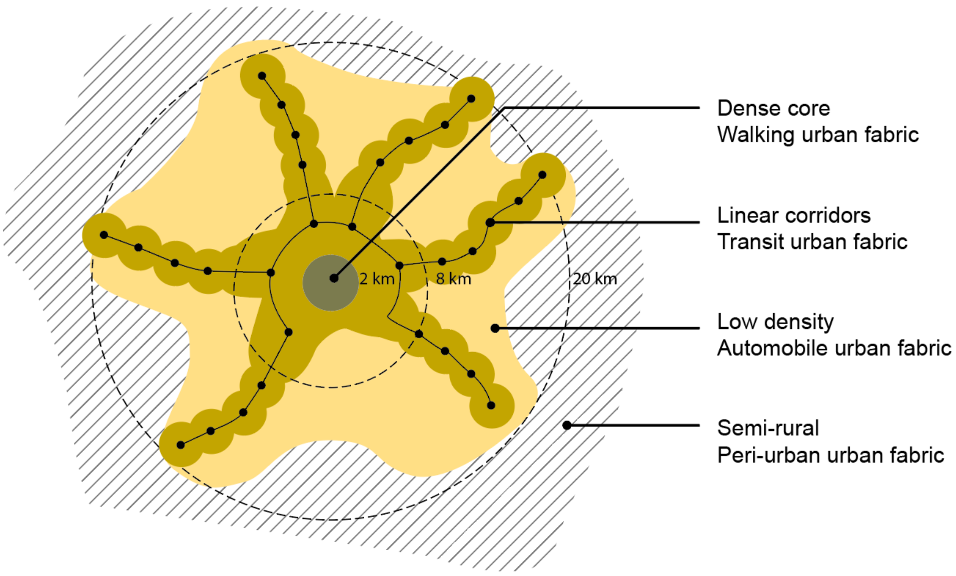


Figure 2. Conceptual city plan illustrating the spatial arrangement of the four urban fabrics relative to one another. Source: Adapted from Newman and Kenworthy (2015).

service dormitory suburbs, and most dwellings are villas set in gardens, usually served by freeways rather than trains. "Human society and the beauty of nature are meant to be enjoyed together" according to Howard (1902, p. 17), private vehicles and the mobility they offer, were responsible for unlocking vast expanses of land to enable many to access this reality in the suburbs. But increasingly, as the limits to suburban sprawl are realised in larger cities, compact city policies lead to ever smaller plots of infill development that erases the garden qualities of the suburbs, with many unbuilt areas 'hardscaped' to support vehicle infrastructure e.g., setbacks, driveways and car parking (Breheny, 1997; Hall, 2007; Newton & Glackin, 2014)—not always with land allocated for natural systems. Car dependent cities (dominated by automobile fabric) have around 30% of their urban space in bitumen, with more than eight car-parking spaces per vehicle (Newman & Kenworthy, 1999).

4.1.4. Peri-Urban Urban Fabric

Peri-urban areas have many of the characteristics of automobile urban fabric. Because peri-urban areas are the interface between urban and rural landscapes, land allotments tend to be larger, varying between suburban clusters and semi-rural landholdings. It is a zone of transition, where relatively cheap land is largely occupied by commuters, 'big-box' retail and some industrial activity, all connected to the urban centre via arterial roads and highways. Yet the peri-urban landscape tends to retain substantial remnant vegetation, cultivated lots and gardens (McKinney, 2006). As cities grow outwards these remnants are often displaced by more homogenous automobile urban fabric.

The limits of car dependent development models (e.g., automobile and peri-urban urban fabric) are now being recognised based upon the environmental (e.g., fuel use), economic (e.g., time and infrastructure costs) and social (e.g., congestion, social isolation) issues that result (Newman & Kenworthy, 2015; Urry, 2004), and have driven a planning backlash toward compact cities and the current preference for urban infill (Thomson & Newman, 2017). However, infill has its own limitations, not least the disappearance of gardens, but also the displacement of urban ecology and other ecosystem services that occur as more ground is taken over by development. Such losses are beginning to be measured as part of urban planning performance, especially for the urban heat island effect (Ding, 2019).

Urban fabrics are recognisable as urban morphological patterns of development within cities. They effectively represent an urban development intensity gradient, where the urban intensity is a function of the dominant transport pattern (Newman & Kenworthy, 1989, 1999). Typically, urban greenery (outside formal parkland) is inverse to urban density. Peri-urban and automobile urban fabric have the greatest proportion of undeveloped ground and more potential for urban greenery, contrasting with the denser walking and transit urban fabric with less undeveloped land available for introducing GI though this is not always the case as wealthy dense areas of cities are often heavily replete with street trees and small urban parks (Newman & Kenworthy, 2015).

4.2. Could GI and BU Integrate Ecological Cities and Resource Efficient Cities?

If we overlook the idealised garden city plan and instead focus upon the conceptual principles, such as access to nature, nutrient cycling, local food production and other ecological principles, Howard's vision seems highly relevant today, even though the drivers for change may have shifted from repairing the social ills of smoky slums to addressing sustainability and resilience challenges. Clark (2003) provides a fascinating account outlining the conceptual and political foundations of Howard's vision and concludes that "Howard's work remains a model for a sustainable relationship with nature, as garden cities offer a possible direction on the route to creating a future in which human society and nature can successfully coevolve" (Clark, 2003, p. 96).

A vision for achieving this has been outlined in literature on biophilic cities (Beatley, 2009; Beatley & Newman, 2013; Soderlund & Newman, 2015), and socio-ecological urbanism (Marcus et al., 2019). But the challenge remains: how is it possible to reconcile growing demand for urban land and the need for compact eco-efficient sustainable cities and urban nature with its multiple ecosystem services? New science and engineering is creating more opportunities for GI and BU to be built into the actual fabric of cities, not just the land between the built environment fabrics. Andersson et al. (2014, p. 450) note that "cities hold unexplored potential for new urban spatial designs that integrate ecosystem services in the built environment, for restoring degraded ecosystem functions through complementary designs of land uses and urban green structures." As we outline in the next sections, there is great potential for the (re)integration of GI and BU into new and existing urban areas once planners recognise the availability of the new scientific tools and how to apply them in different parts of the city as the city is made up of different urban fabrics, each with different potential for using the new tools. Previous studies outlining urban fabrics (Newman, 2020; Newman & Kenworthy, 2015; Newman et al., 2016; Newman, Thomson, Helminen, Kosonen, & Terämä, 2019) emphasise urban structure and form, rather than GI and BU. In the next section we describe how urban fabrics may be useful as a typological approach to aid planning decisions relating to integration of GI and BU.

4.3. GI, BU and Urban Fabrics

The GI and BU in different parts of the city will necessarily vary due to the different availability of space and the different value of land. Outside of the centrally planned regional open space structure, most GI is the result of thousands of micro scale decisions, as codified in planning regulations. The generic urban areas of built form, streets and infrastructure, those cellular pieces that collectively form the urban morphological patterns comprising the vast bulk of any city, i.e., the 'urban fabric,' are where urban planning is able to use these new tools.

Recognising that almost every city is made up of a range of urban fabrics, will help policy makers write supportive regulations to aid GI/BU uptake. Formalising such a process could incentivise and empower citizens and individuals to integrate much needed urban ecology, even in established areas. We provide some initial ideas relating to the type of approaches that can be used. Comprehensive policies of course must respond to the local bioregion, but the spatial characteristics due to land availability and development density are much more generalisable.

Figure 3 summarises the urban fabric characteristics, and key GI/BU opportunities and challenges for each. It indicates how planners and designers could develop a typological approach for urban nature interventions in any part of a city, by matching GI/BU responses to the relevant urban fabric.

Traditional GI, e.g., gardens, swales, wetlands that occupy undeveloped ground, will be most appropriate in low-density peri-urban and automobile urban fabrics. They are also the least technical and least expensive to deliver and maintain, though they cannot be neglected either. By contrast, in the denser walking and transit urban fabrics where space is limited, more technical BU approaches allow for the integration of green and blue infrastructure where previously it was not possible. BU innovations such as green roofs, green walls, engineered biofiltration strips and the like tend to cost more, but publicly delivered projects will benefit from higher land taxes per hectare, similarly private projects benefit from greater density with higher site yields allowing any additional costs to be ameliorated over multiple dwellings. Urban nature also increases property value (Colding & Barthel, 2013; McDonald et al., 2016), so in

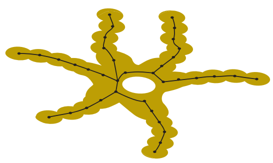
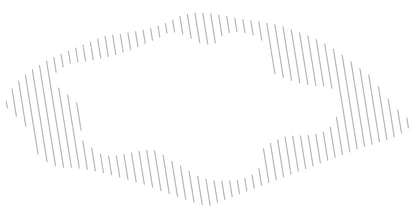
Urban Fabric	Characteristics	GI / BU opportunities & challenges
Walking Urban Fabric 	• Central urban core • Dense, mixed-use areas • Generally more than 100 persons per hectare • Dense non-residential services in close proximity to residential population	• Limited space for GI outside public realm (e.g. parks and streets) • Greatest GI opportunity in public realm (e.g. biophilic streets, parks) • Potential to incorporate BU in/on private built form as green roofs, green walls, detention basins etc. • Higher tax revenue per hectare allows higher public GI/BU budget for projects/maintenance
Transit Urban Fabric 	• Typical densities between 35 and 100 persons per hectare • Higher density walking fabric still remained around transit stops • Clusters of services at activity nodes	• Fairly limited space for GI outside public realm • Moderate potential for GI/BU in private realm e.g. gardens • Linear corridors along transit routes and biophilic streets • BU in/on built form
Automobile Urban Fabric	• Low population densities of less than 35 persons per hectare • Typically single dwellings on larger blocks with gardens • Monocultural land uses • Sparsely distributed services	• High potential for private on-plot GI e.g. gardens • The lower the density the greater the private on-plot GI opportunities • Lower density areas have less land tax per hectare therefore less income for public GI projects projects/ maintenance
Peri-urban Urban Fabric 	• Very low densities on the urban fringe • Predominantly residential development on large blocks • Remnant fragments of cultivated and ecological land • Minimal service provision	• Considerable private on-plot GI opportunity • Dominance of private realm makes co-ordination of GI challenging • Reduced land tax per hectare provides less income for public GI projects projects/maintenance

Figure 3. Basic characteristics of four urban fabrics and GI/BU potential.

addition to ecosystems services, such projects may be seen as investments. The GI/BU potential of each urban fabric is briefly described below.

Peri-urban areas are the least intensely developed of the urban fabrics. Therefore peri-urban areas have the greatest potential to incorporate well considered GI. Remnant high value ecosystems can be mapped and ideally retained as connected habitat corridors, with new development preferentially located on more degraded patches (cf. McHargian sieve mapping). Similarly, strategically located degraded patches can be identified and enhanced through regenerative design approaches that seek connect isolated fragments into functioning GI corridors (cf. Lyle, 1996). Regional green infrastructure will need coherent strategic and statutory guidelines to enable any owner or developer to integrate these GI features into their developments.

Automobile fabric with its low-density housing set in gardens, presents considerable possibility for GI, but typically interventions will be smaller scale due to ownership boundary constraints. As a result, it is rare to find extensive areas of private land in the suburbs exhibiting cohesive GI qualities, typically such provision is highly fragmented. In those areas where the urbanised systems of buildings and concrete/asphalt limit opportunities for GI, then BU should be considered as a way to revive the natural systems. As with peri-urban areas, the GI features will need to be established with owners to enable the full potential of GI and BU outcomes.

Transit fabric comprises linear development corridors along mass transit routes, density is high around stations. The linear nature of these corridors lends itself to linear GI where possible, but it will need significantly more BU to enable its ecological systems to be more fully integrated into the urban fabric. For example, linear green parks, avenues of trees, water sensitive urban design in the form of swales and biofiltration strips can be designed into the street network as 'biophilic streets' (Cabanek, Zingoni de Baro, & Newman, 2020; Figures 4 and 5). The key is to see that the dense, built environment features can have biophilic features built into them so that water flows, air flows, canopy shading and regional biodiversity are part of the design of any site. This is a multi-skilled planning and design challenge.

Walking urban fabric is the most intensely developed urban fabric. The high density of land use and population leave little room for GI outside those areas set aside for public realm, i.e., parks and streets. Yet, the high population density makes the importance of GI all the greater. Dense urban areas are more vulnerable to climate change impacts such as flash flooding (due to increased impermeable surfaces; Wamsler, Luederitz, & Brink, 2014), increased urban heat (due to greater thermal mass; Norton et al., 2015), and increased psychological stress due to greater intensity of activity and need to access nature in daily life. The lack of space, which formerly limited GI opportunities may now be overcome through BU approaches that allow urban nature to be integrated into dense areas. BU thereby can help mitigate these climate change risks (Beatley, 2009) if urban planners can build it into their strategic and statutory systems. Widespread uptake of BU approaches is beginning

Figure 4. Central Malmö, Sweden: Biophilic streets with water sensitive urban design plus stratified street tree planting. Source: Authors.

Figure 5. Vauban, Freiburg, Germany, a medium density transit urban fabric serviced by tramline with lawn base to mitigate noise and allow water infiltration surrounded by multiple house-based biophilic features. Source: Authors.

to show how these dense areas can incorporate patches of urban nature, though very few have related their biophilic features to the underlying natural systems that can together integrate a resource efficient and ecological aspects right across the city.

Dense walking urban fabric has less adverse impacts upon ecology due to reduced encroachment upon valuable ecological or arable landscapes (Seto, Güneralp, & Hutyra, 2012), and the reduced ecological footprint (i.e., eco-efficiency) of dense urban areas (Newman et al., 2017; Thomson & Newman, 2018b). But making dense urban areas desirable as a place to live is of critical importance. In addition to reducing ecological footprint, GI/BU integration can enhance liveability through improved access to nature.

As cities become denser over time, GI typically reduces. But planners can mandate increased ecological function as cities increase in density through greater use of BU—as happened in Singapore (Box 1). Using a planning policy known as Landscaping for Urban Spaces and High-Rise programme, Singapore's Urban Redevelopment Authority imposes green space replacement requirements for new buildings in high-density areas to encourage accessible urban greenery (Thomson, Newton, Newman, & Byrne, 2019). Floor area bonuses are also given to incentivise high quality green space provision in new developments, thus allowing building density to increase as in response to increases in GI/BU density. Thus, McHargian ecological functions can be analysed for even the densest parts of cities and built into the fabric of buildings, urban spaces and roadways to achieve many of the same ecosystem services that would have been there without the built fabric.

5. Discussion

5.1. Garden Cities of the 21st Century

Ebenezer Howard, who grew up on a farm, argued that garden cities were the key to "restore people to the land" (Clark, 2003, p. 91) his intention was to foster a reconnection between people and nature. In this article we have described the use of urban fabrics as a potential typology to base more appropriate GI/BU components into cities. We argue that GI/BU responses should respond to the underlying opportunities presented by each urban fabric to create a new breed of garden cities for the 21st century.

It is important to distinguish that what we are describing is about finding space in the city from a planning perspective, because the spatial development patterns of all modern cities we have studied can be categorised into the dominant urban fabrics or variations of them (e.g., Newman et al., 2016). But this space need not be limited to the ground, rather like a forested ecosystem, it can be on vertical surfaces and on different layers that are created by different urban fabrics. However, the GI/BU response remains highly contextual, and the most appropriate intervention must be determined by ecologists, landscape architects and allied professions to ensure a good fit to the bioregion, microclimate, topography, culture, governance and

Box 1. Singapore's biophilic urbanism tools as the basis of GI.

Green infrastructure is using ecological systems to enable the management of water, air, waste and open space. In the ecological cities paradigm this means setting aside space to enable trees to cool the urban heat island, daylighting and meandering stormwater flows into creeks from concrete channels and pipes, having natural open spaces that enable biodiversity and human- nature interactions and more. But these opportunities are impossible to introduce into city spaces that are densely constructed because of the need to create agglomeration economies and in recent times to regenerate the resource-consumption of low- density areas.

Singapore was a leader in showing how biophilic urbanism could bring green infrastructure back into dense urban fabric. It did this by creating a strategy, then developing the science of the species and the engineering of how green walls and green roofs could be built in their climate. It then set up demonstrations of all these and also how to close canopies on roads where only small spaces were available for planting, and creating opportunities for creeks to be created from piped stormwater, even where the space was very restrictive. It finally created the manuals that set out how to create all the ecological functions on the actual built urban fabric and regulations that set out how a green floor space ratio could be achieved in the dense central areas of the city.

The result has seen biodiversity regenerating, storm water management made easier and cleaner, urban heat island effect reducing, improved land and rent values in buildings with biophilic facades and roofs, and increased pedestrian activity in areas where nature is more obviously accessible. The health benefits have also increased.

At the same time Singapore has not reduced its development in both central urban regeneration and in new areas where both biophilic strategies and traditional green infrastructure strategies have been used such as in the new Punggol redevelopment corridor.

Sources: Newman (2014) and Blagg (2012).

maintenance strategies and other local considerations. A typological approach using urban fabrics can offer a generalisable guide for finding and allocating space in contested urban areas to facilitate GI/BU integration that could be replicated globally, however, the type of GI/BU intervention will require highly contextualised local responses that see dense urban areas as opportunities just as rich in potential natural habitat as those that are less dense.

5.2. Greening Cities to Reconnect Citizens to Nature

Designing GI/BU into cities is important for the increased urban resilience provided by a range of ecosystem services such as urban cooling, stormwater peak flow mitigation, psychological benefits of urban greening and other ecological outcomes; however perhaps more significant is the role that urban GI/BU provides for reconnecting cities and their citizens to the biosphere, whereby citizens become urban stewards of nature (Andersson et al., 2014). Stewardship that involves social networks as well as management and maintenance, that collectively foster the type of ecological mindset that builds interest and agency for a societal transformation toward sustainability. Urban planners tend to focus on housing, transport and economic growth, not protecting ecological and cultivated land, water and biodiversity (Forman & Wu, 2016). However, placing greater emphasis upon the integration of GI/BU into the various parts of the city can support local planning objectives, while also addressing larger goals of sustainability as set out by the New Urban Agenda and the Sustainable Development Goals (United Nations General Assembly, 2015).

5.3. Aligning Other Citizens and Actors

Because urban planners both shape policy and approve development within cities, they are key actors to enable widespread uptake of urban GI/BU. Planners can develop policies to encourage different GI and BU strategies in peri-urban, automobile, transit and walking urban fabrics, but ultimately citizens and other actors (e.g., developers, community leaders, politicians) will be necessary for successful implementation of urban greening projects. Local citizens often act as custodians of their local green space, likewise they will know much more about local ecology and how it can be enhanced than most urban planners, hence citizens should be involved early on in the process of integrating resource efficiency and ecological planning paradigms using GI and BU tools.

Context is critically important, as different cities have different needs. Therefore, when considering actions toward meeting the Sustainable Development Goals (particularly Sustainable Development Goal 11 on cities), decisions will need to be considered in terms of the various co-benefits and trade-offs (Akuraju, Pradhan, Haase, Kropp, & Rybski, 2020). Context matters, not only between different cities in a particular ecological region where partnerships in GI planning across multiple boundaries will be required, but also in different parts of a city where the use of urban fabrics as a planning lens is useful to help inform policy choices. Partnerships across local governments will be essential to use GI and BU tools across the whole city. In dense walking urban fabric, new biophilic strategies will be most appropriate as they will allow, and support, retention of those benefits that are afforded by high-density, compact urban areas. By contrast, automobile urban fabric will benefit from more traditional GI approaches that can be accommodated in less intensely developed urban fabric. However, as outlined above, both sets of tools overlap and will be needed to enable local ecology and more system-wide ecology to be enhanced.

Presenting GI/BU choices as a typology grounded in urban fabrics opens up a range of much more focussed discussion points based upon trade-offs and co-benefits that can be used to inform deliberative processes with citizens, politicians and other actors. But it is important to also note that just having a strategy for accommodating GI/BU within a city will not be sufficient without having a clear strategic McHargian concept plan across the city/region, and without considering the essential alignment of agencies, organisations, and citizens who ideally will co-ordinate to ensure clarity around the long-term management and maintenance of new ecological assets. For example, Pincetl's (2010) detailed case study on the Los Angeles million tree initiative offers a glimpse into some of the actor alignment co-ordination challenges to be overcome when attempting to implement novel, large scale, centralised (i.e., government led) urban tree greening programs.

6. Conclusions

This article describes how the two apparently conflicting sustainable planning paradigms of resource efficient cities (pro-density) and ecological cities (anti-density) can be resolved. The cause of the conflict was finding space to maximise urban nature, but density need not be seen as a barrier now to integrating GI, rather with new scientific and engineering approaches nature can be integrated into any urban area. A lack of available space in dense areas can be overcome by BU tools that allow nature to be integrated on or over buildings and infrastructure e.g., biophilic streets, green roofs and green walls. However, to maximise urban nature requires urban planners to consider what GI/BU components are appropriate to the prevailing development pattern. Recognising that different parts of the city have different potential can assist with decision support and policy creation for a more nuanced GI/BU response. A typological classification based upon the dominant (or expected) urban fabric can inform planning policy and support the work of landscape architects, civil engineers, developers and related actors to tailor appropriate GI/BU tools. This in turn will help operationalise ecological and resource efficient cities that could lead to a flourishing of garden cities in the 21st century.

This draws upon and embraces aspects of the garden city as envisaged by Howard over 100 years ago—aspects of which are as relevant now as ever but now includes new science and technology as well as new understandings of how cities work that can help bring these old principles to life. There are numerous reasons for why our cities need this combination of the old and new, including:

- The climate adaptation and resilience benefits of ecosystems services are now a critical agenda for cities in the 21st century;
- The psychological benefits of biophilic environments to enhance quality of life and mental well-being, particularly within megacities where large conurbations can make it difficult for citizens to access nature, and perhaps most importantly;
- Re-introducing nature to cities to provide opportunity for citizens to engage with nature, thus increasing their eco-literacy.

The drivers are there for planning policy revision, just as they were when Howard's garden city concept took hold within the professions; but even with policies in place, implementing such a vision will require many actors from science and urban planning working collaboratively together:

- Botanists, ecologists, hydrologists and related scientific expertise, plus the façade engineers who can help to identify the most appropriate solution for the given bioregion and the particular urban fabric, and;
- Designers to conceive and document localised urban interventions, plus the municipal support or citizen collectives to maintain and manage urban GI/BU.

While multi- and trans-disciplinary approaches will be needed to effectively deliver integrated resource efficient and ecological cities, urban planning is the only profession capable of strategically and systematically providing the conditions to embed GI into all parts of the city. This will likely prove challenging for many traditionally trained urban planners, as it falls outside the usual scope of conventional planning practice; however, the combined mitigation, adaptation and psychosocial benefits of incorporating GI/BU into all parts of the city justifies the efforts required to change policies to help our cities rise to meet the grand challenges of the Anthropocene as well as the small challenges of creating competitive and attractive urban economies and communities.

Transformation of urban systems toward resource efficient energy, water and waste systems is central to the future of the planet, but equally important is an ecological approach to maximise nature within cities. These agendas may be perceived by some as conflicting. But just because resource efficient approaches to materials and resources benefit from a compact urban city agenda, this *does not* mean ecological systems must be displaced within the city. Rather, as this article shows, urban fabrics offer guidance on how GI may be integrated by using BU approaches in dense urban regeneration projects, and in traditional ways in low-density areas. Thus, reducing land take and resource use, while simultaneously regenerating the local ecology.

Acknowledgments

The authors thank the three anonymous reviewers for suggestions that helped improve the article. Giles Thomson would like to acknowledge financial support through the Knowledge Foundation (KK-stiftelsen) in Sweden.

Conflict of Interests

The authors declare no conflict of interests.

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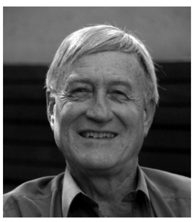

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Urban Planning (ISSN: 2183-7635)

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