Small-Scale Urban Green Infrastructure

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Urban green infrastructure (UGI) such as green roofs, green facades, public parks, urban forests, urban wetlands, and unmanaged green sites, provide nature-based solutions (NBS) that offer a promising avenue for climate change adaptation in cities to reduce the negative environmental impacts of urbanization, such as the urban heat island effect and altered precipitation patterns. UGI supports a wide range of ES at different spatial levels including but not limited to provisioning (e.g., food, and freshwater), regulating (e.g., urban temperature regulations, noise reduction, air purification, pollination, runoff mitigation, and waste treatment), socio-cultural (tourism, recreation, cognitive development, social cohesion), and supporting (e.g., habitat for biodiversity diversity), with fewer documented health benefits (e.g., good health, mortality).

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1. Urban Green Infrastructure and Ecosystem Services

Green infrastructure (GI) is a relatively new concept, and several studies have proposed different definitions for GI. The two most cited definitions are from Benedict [1] who defines GI as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations”, and the European Commission [2], which defines GI as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ES. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings”. According to these definitions, key characteristics of GI, including multifunctionality, ecosystem services (ES), ecological networks, connectivity, and multiscalar, serve as boundary concepts among various policymakers, planners, and researchers to guide UGI planning and designing [3].

Urban ecosystem services (UES) have multiple benefits for human health and well-being in the face of rapid urbanization, land-use transformation, and climate change crisis [4]. ES can be defined as “the benefits people obtain from ecosystems” [5]. UES is supported by a diverse green infrastructure type including but not limited to parks, urban forests, farmlands, vacant lots, and gardens. UES can be divided into four categories according to the Millennium ecosystem assessment [5]: provisioning services (materials obtained from ecosystems), regulating services (benefits obtained from the regulation by ecosystem process), habitat or supporting services (essentials to produce all ES) and cultural services (non-material benefits obtained from ecosystems). Research suggests that small-scale green infrastructure can moderate the negative environmental impacts of rapid urbanization and climate change by contributing to recreation, mitigating air pollution, cooling surface, and air temperatures, and retaining stormwater run-off [6]. For example, green roofs and walls may improve air quality and flood control management or street trees can reduce exposure to pollution in urban areas [7][8][9]. Moreover, community gardens in urban neighborhoods not only provide food but can also have health, social and aesthetic benefits for the local community [10][11][12]. Green spaces and urban trees can also mitigate air temperature through transpiration, evaporation, shading, and modifying wind-flow mechanisms [13]. A study by Peschardt et al. [14] indicates that small-scale green spaces have socializing benefits because they provide spaces for neighbors to interact, whereas other services such as noise reduction and carbon storage are less associated with small-scale green spaces compared with large-scale green infrastructure due to their lower compactness or density.

Table 1 summarizes the ES provided by six types of small-scale GI examined in this study. As can be seen, small-scale UGI provides a wide variety of benefits, albeit some UGI types, such as community gardens, may provide a larger range of services than others.

Table 1. Urban ES provided by six studied small-scale green infrastructures.

ES	Some Examples of UGI and Their Impacts in Literature
Provisioning	Community gardens can address food security in urban areas [15][16]
Supporting	Street trees offer key conservation opportunities for pollinators [17], they also reduce the negative effects of urbanization on birds [18]; green roofs can have ecological significance by attracting and supporting urban fauna [19]; vacant lands can support insects' habitats [20]
Regulating	Vacant lands have cooling effects in urbanized areas [21]; green roofs have large impact on the urban heat island effect, positive effect on street canyon air quality, and stormwater management [22][23][24]; rain gardens may provide considerable carbon potential, offsetting the whole carbon footprint [25]; street trees can reduce air quality depending on the aspect ratio as well as stormwater [26][27]; community gardens can reduce surface runoff [28]
Socio-Cultural	Small parks offer health benefits [20][29]; green roofs offer recreational and experimental benefits for residents [30]; community gardens as learning environments for sustainability [31]; vacant lots may provide social and cultural values for local communities [32]

2. Urban Green Infrastructure and EDS

While UGI has several benefits, it also sometimes produces EDS that are frequently overlooked [33]. The concept of EDS refers to the negative impacts that ecosystems can have on humans and their environs [34]. According to Lyytimaki and Sipila [34], EDS are "functions of ecosystems that are perceived as negative for human well-being" and can be brought on by natural or political occurrences such as floods, earthquakes, wildfires, or conflicts. For example, small-scale UGI such as street trees may provide allergies associated with grass pollen and damage to properties [35][36][37][38]. Some species release a significant amount of biogenic volatile organic compounds (VOCs), which, when combined with nitrogen oxides (NOx), can create particulate matter, secondary organic aerosol, and ozone, which exacerbate respiratory diseases such as asthma [39]. In addition, research shows that the risk of vegetables and soil contaminated by heavy metals and pollutants in community gardens and green roofs can be considered EDS [40]. There is no agreement on how to classify EDS in relation to ES, despite the fact that certain research has split it into various groups [31][41][42][43][44]. Better understanding of the conditions under which EDS arises will help policymakers, practitioners, and communities reduce these negative impacts. While urban areas depend on ES, understanding disservices are of paramount importance from a governance lens. Since EDS reduces public support for UGI, it is important to reduce these negative impacts to optimize UGI for sustainability. For example, in the Mediterranean region, the ornamental patterns of the urban areas imply significant pollen risk from woody species such as plane trees or cypresses, as the most allergenic ornamental species [45][46]. Some studies such as those conducted by Von Döhren and Haase [30] and Sousa-Silva et al. [46] have provided a reliable overview of the environmental and health issues produced by different types of urban trees. **Table 2** summarizes some examples of EDS provided by six types of small-scale GI examined in this study.

Table 2. Urban ecosystem disservices are provided by six studied small-scale green infrastructures.

EDS	Some Examples of UGI and Their Impacts in Literature
EDS	Tall and leafy trees may block the views [47]; Vacant lands may be unsafe and ugly [47]; Some plant species may create allergenic pollen [48][49][50]; Tree roots may cause sidewalk pavement problems [51]; Community gardens may get contaminated by greywater irrigation from contaminated drainage channels or streams [52]; Increasing UGI results in an increase in hornet species [53]; Urban trees produce green waste resulting in public health issues [7]

3. A Need for New Governance Approaches

Enhancing urban resilience and sustainability in the face of “wicked problems” are key challenges for UGI governance [53]. According to Andersson et al. [54] and Jerome [55], small-scale UGI can contribute multiple co-benefits to support a wide variety of ES. However, there are still some barriers and uncertainties to governing and managing different types of GI worldwide.

One of the important challenges for governance in existing small-scale UGI, such as pocket parks or vacant land uses, is that they can be temporary or short-term land uses. For example, a study in Detroit, Texas found that ragweed populations are more common in vegetated vacant lots, making the transition management of these lots crucial to avoiding significant effects on allergenic pollen burdens [56]. Thus, if cities rely on the ES that these spaces provide, there is a need for governance mechanisms that either provide long-term security for these spaces or support a more adaptive, flexible, and dynamic governance approach to cope with the temporary negative consequences of these spaces [57][58]. Kabisch [59] states the major challenges for green infrastructure governance in Berlin as financial constraints, loss of expertise, and low awareness of such spaces’ benefits at the local scale. Fox-Kamper et al. [60] found the major barriers to community garden governance include unsecured land tenure, community engagement, and lack of long-term governance support. A study by Guitart et al. [61] shows that the main challenge for community garden governance in the United States is land tenure where gardeners lack long-term access to land. Furthermore, some scholars have highlighted the issue of changing governance settings and GI data inconsistency as some of the most important challenges GI are facing [62]. Undoubtedly, one of the most important barriers to implementing GI, such as rain gardens, is their costs. These facilities can be expensive to install and maintain, which in turn reduces the willingness of planners and owners to shift toward them [63].

Moreover, urban governance is challenging given environmental justice (EJ) issues in terms of UGI equitable distribution, transparent procedures, and sufficient recognition of various actors' needs and perceptions [64]. Availability, accessibility, and attractiveness of small-scale UGI for different social groups and inhabitants are among the most important issues that EJ research has recently addressed [65][66]. For instance, Sanchez and Reames [67] address spatial equity in green roof distribution in Detroit, MI, and show that green roofs were concentrated in the wealthiest part of Detroit's urban core with a predominantly white population. Consequently, an emerging focus in environmental governance is how different governance approaches can broaden access and participation to diverse social groups, particularly marginalized or vulnerable groups. A potential opportunity for small-scale UGI to promote environmental justice lies in its need for local governance, which can place decision making in the hands of local communities and give them ownership over these spaces. In addition to promoting equitable governance, local ownership may reduce disservices, such as green gentrification, which has been identified as a concern by researchers and non-profit sectors in recent years [68]. In other words, an equitable distribution, experience, and understanding of UGI throughout the cities is an important goal of UGI governance.

Significant shifts have occurred within environmental decision making on UGI in the past 20 years. These shifts have yielded collaborative and bottom-up management approaches to guarantee future success in the face of rapid urbanization, climate change, and major societal disruptions, such as the COVID-19 pandemic. UGI government styles based on centralized decision making, public budgets, top-down, and bureaucratic arrangements have been replaced increasingly by new horizontal approaches of environmental decentralized governance focused on the fluidity between top-down and bottom-up approaches. This new emerging paradigm shift largely emphasizes the concepts of flexibility, collaboration, coordination, awareness, adaptation, inclusiveness, knowledge generation, and transparency [69][70][71][72][73]. As a result, a range of new democratic governance approaches is in use under conditions of uncertainty, complexity, instability, and unpredictability to include different stakeholders' voices in the UGI decision making process and problem-solving. The uncertainty and complexity of managing ES at the local scale is related to socio-political (e.g., population growth), economic pressure (e.g., shrinking budgets), and environmental changes (e.g., climate change). New UGI governance approaches are intended to better address multiple stressors of urbanization and climate change by utilizing ES and harnessing disservices [74][75][76][77][78]. Over the last several decades, a wide variety of governance arrangements have been proposed, including "state governance" of publicly owned vacant lands and community gardens, and "networked governance" of public-private partnerships for local parks to the "self-governance/marketbased" approach of guerilla gardening. However, examining the applicability of different new governance approaches and policies to co-create and co-manage UGI is an important research direction.

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