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Review

The multifunctionality concept in urban green infrastructure planning: A systematic literature review

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ABSTRACT

Urban green infrastructure is critical for providing a wide range of ecosystem goods and services that benefit the urban population. Past studies have suggested that multifunctionality concerning urban infrastructure services and functions is a prerequisite for targeting effective and impactful urban green infrastructure. Moreover, urban green infrastructure with multiple functions can offer socio-economic and environmental benefits. However, there has been a knowledge gap in the planning literature to elaborate multiple ecosystem functions in urban green infrastructure. In particular, existing methods and approaches are lacking for quantifying and monitoring such ecological services and biodiversity in urban green infrastructures at different spatial scales. Therefore, this research aims to review studies focusing on the multifunctionality concept in urban green infrastructure planning. The study highlights the current status and knowledge gaps through a systematic review. Our analysis revealed that current studies on green infrastructure multifunctionality have focused on five main themes: 1) planning methods for urban green infrastructure, 2) assessment approaches of urban green infrastructure, 3) ecosystem services and their benefits, 4) sustainability and climate adaptation, and 5) urban agriculture. The study found that the five themes are somewhat connected to each other. The study has revealed a knowledge gap regarding incorporating multifunctional green infrastructure in the planning principle. The results suggest at least five critical elements to ensure multiple functions in urban infrastructure. The elements are spatial distribution, optimal distance, integrated network, accessibility, and public participation and engagement. The study further recommends research directions for future analysis on green infrastructure multifunctionality that are critical for urban planning.

1. Introduction

Over the past 20 years, numerous concepts have emerged to address the overarching challenges of integrated planning for green spaces, including nature-based solutions (NBS) and (blue-) green infrastructure. NBS aims to promote natural urban development processes to help overcome the challenges of renewable energy, food security, water resources, and climate change (Pauleit et al., 2019). NBS suggests that urban infrastructure development should support natural processes to gain broader sustainable impacts and benefits. In this regard, urban green infrastructure is critical for NBS adoption (Sugiyama et al., 2008) in order to contribute to crucial functions such as clean air and water, stormwater management, biodiversity, and beautiful landscapes (Benedict, Mcmahon (2002), Hansen and Pauleit, 2014, Taylor et al., 2021, Tzoulas et al., 2007). Past studies denote that urban green infrastructure can offer multiple functions for ecosystem and biodiversity benefits (Beatley, 2012, Benedict, Mcmahon (2002), Bianconi et al., (2018), Sugiyama et al., 2008). Therefore, there has been a growing concern by many policymakers to plan and build up UGI in the regions considering multiple functions to gain greater ecosystem and biodiversity benefits. With functions, we refer to the processes providing the benefits as ecosystem services. Unfortunately, these terms often are used as synonyms and are frequently mixed up with system properties. As multifunctionality is a broad concept and there is no general agreement on what constitutes a function (e.g., Garland et al. (2021), scientific clarification is required (Manning et al., 2018).

Cities worldwide maintain different UGI features as part of NBS. Those are, for example, green roofs, permeable green surfaces, green

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paths and streets, ponds, parks, and wetlands (Demuzere et al., 2014, Elliott et al., 2020, Rusche et al., 2019). These infrastructures facilitate a mix of human and natural systems to promote environmental sustainability. According to several studies (e.g., see (Winslow, 2021), the feature of green infrastructure (GI) comprises seven principles: 1) comprehensive combinations across urban-rural areas and settings, 2) integration with other urban infrastructure, 3) multifunctionality providing for multiple services, 5) connectivity of the form and functions in the landscape, 6) multiscalar for natural and cultural processes and 7) transdisciplinary combining expertise from different disciplines.

Interestingly, numerous studies have suggested multifunctionality as the most critical principle when it comes to providing multiple uses of urban infrastructures for the same area through land sharing (Selman, 2009, Tzoulas et al., 2007). Multifunctionality indicates the multiple functions in which urban infrastructures can provide to benefit people and the ecosystem (Hansen et al., 2017). The benefit often associates with social, economic, and environmental aspects. For instance, a green roof can protect the building from rainfall and stormwater management and provide a beautiful landscape. In parallel, a green roof prevents the pollutant load of rainwater, decreases the urban heat effect, improves the insulation of the building, and provides a habitat for a variety of species (European Commission, 2012). Ultimately, the multiple functions of green roofs can relate to stormwater management, air quality, noise reduction, urban heat, public health, and well-being. These functions provide ecological, social, and economic benefits to green spaces and infrastructure (Hansen and Pauleit, 2014, Roe and Mell, 2013).

Past studies further overview the strong linkage between UGI multifunctionality spatial planning (e.g., (García et al., 2020, Živković et al., 2019). According to Živković et al. (2019), spatial planning provides an overview of green infrastructure multifunctionality (GIM) through four aspects: 1) interconnection across spaces, 2) multiple activities under different needs, 3) different functions at different times, and 4) the variety of services the space provides to meet socio-economic and environmental requirements. Urban planners and policymakers, however, face the challenge of identifying the magnitude of multifunctionality based on the trade-offs and synergies in services and functions. Thus, we aim to review the scientific literature that addresses the planning principles of UGI multifunctionality. We are keen to pinpoint the role of multifunctionality in urban infrastructure planning discourses, as based on the authors' understanding, no systematic literature review study has focused on this aspect so far. We expect this study to improve our scientific understanding of multifunctional UGI and be relevant for practitioners and scholars in planning and developing sustainable and liveable cities and urban areas for all.

2. Methodology

This study presents a systematic literature review using the PRISMA reporting system to identify papers addressing the multifunctionality concept in urban spatial planning (Page et al., 2021). We searched Web of Science core collection and Scopus using the string "urban* and (multifunct* or "multiple funct*") and plan* and infrastruct* " without time restrictions, with 28th February 2023 as the final date of search. Relevant papers were identified from 2002 to 2023, and as a result, the

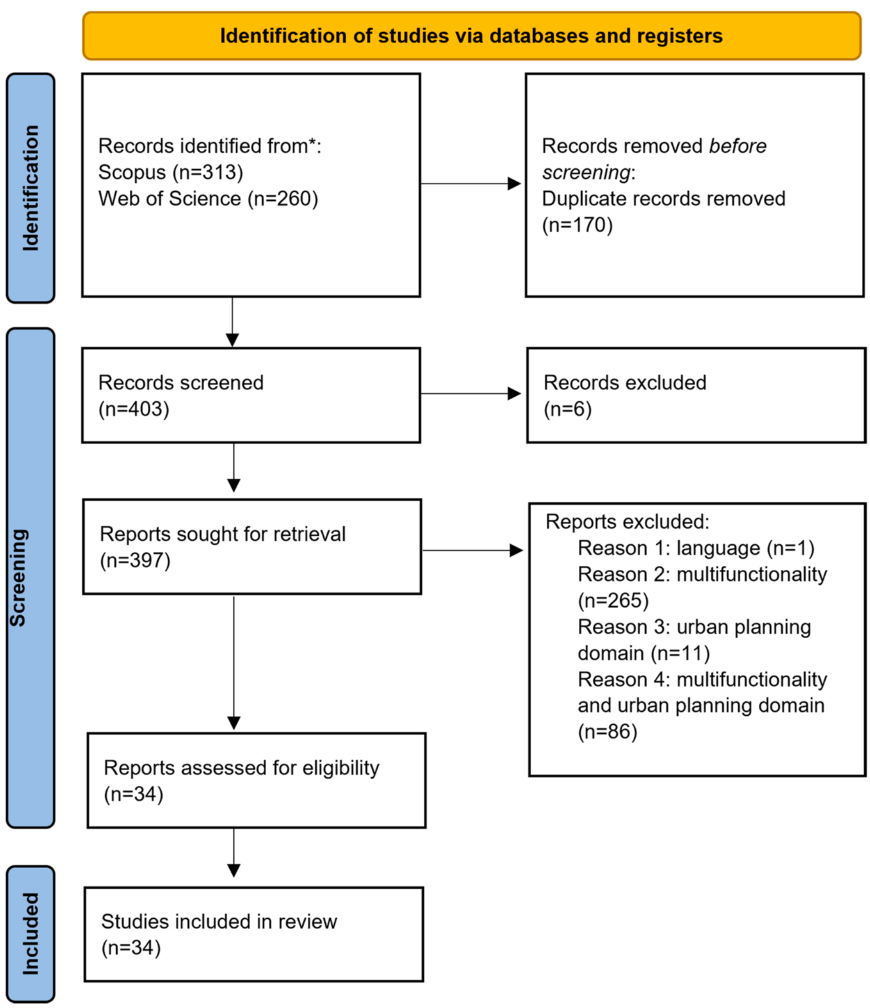

Fig. 1. The steps for screening the selected papers for the systematic literature review (Page et al., (2020)).

analysis included 399 papers in the screening (Fig. 1). In total, there were 134 papers from Web of Science only, 123 papers from Scopus only, and 143 papers in both databases. We also explored the impact of search string composition on identified papers (Table 1). Adding plan and infrastructure terms to the string, reduced the number of papers to less than one-fourth, while the restriction to urban settings reduced the number by an additional one-third. It is important to note that this research acknowledges the limitation of using WoS and Scopus to support a PRISMA analysis. These search engines cannot provide an overview or analysis of the papers' quality. Therefore, it is necessary to assess the quality of the selected papers through the Systematic Appraisal of Quality in Observational Research (SAQOR) to fulfill the gap (Table 2). This approach follows the manual process to verify the paper quality based on information reported in the papers related to sample, exposure or outcome measures, distorting influences and data reporting (Patel et al., 2018).

As a rule of thumb, in the screening process, we exclude a paper if it is not an English-written article, does not address multifunctionality, or does not address the urban planning domain based on title and abstract. This process recommends 34 articles suitable for this research objective (Fig. 1). The remaining papers were then screened on full-text content. We also observed the potential bias of data sources, which can occur during study design, study implementation, and data analysis. Since most data sources do not contain data from individual surveys and interviews, we have found no issue with the potential bias of data sources. Instead, most data collected are from spatial and physical observation and statistical data. We also found no issues related to data analysis in the selected articles. Almost half of the selected articles are theoretical studies, meaning no data is utilised. Thus, the systematic literature review is unbiased and is exclusively based on the search string that we used and ended up with the 34 papers. The authors developed the search string and approach, while the first author did the screening.

For further analysis, we introduced two steps. First, we classified the 34 papers into clusters based on the similarities of several items: concept, terminology, methodology, and keywords. As the number of final papers was low, this was studied qualitatively. In addition, we explored each paper's relation to the clusters and whether a paper is part of a single cluster or multiple clusters. A paper only represented one cluster if it explicitly addressed only one theme. On the other hand, if a paper has an overlapping discussion of two or more themes, we concluded that the paper represents the clusters under the captured themes. We also argue that these identified clusters demonstrate a relation to each other. The quality assessment verified the papers into three levels: adequate (strong), moderate, and unclear (poor). The screening found that the overall quality of the selected journals and papers are mostly adequate (30), while the others are moderate (4).

Table 1
The search string used in this study (see no. 1) and alternative strings to test for sensitivity to specific terms.

No	Search String	WoS	Scopus
1	urban* and (multifunct* or "multiple funct*") and plan* and infrastruct*	273	313
2	urban* and (multifunct* or "multiple funct*")	2353	2057
3	urban* and (multifunct* or "multiple funct*") and plan*	1061	1095
4	urban* and (multifunct* or "multiple funct*") and infrastruct*	390	443
5	urban* and (multifunct* or "multiple funct*") and infrastruct* and green	223	297
6	urban* and (multifunct* or "multiple funct*" or "multiple servic*") and plan* and infrastruct*	281	323
7	(multifunct* or "multiple funct*") and plan* and infrastruct*	552	480

3. Results

3.1. Overview of the green infrastructure multifunctionality research

The term multifunctionality in the green infrastructure concept was reported for the first time in 2002 (Fleury, 2002) according to the used search string. A range of analytical techniques have been used, from descriptive analysis to methodological and conceptual papers. Regarding the geographical distribution of the study case, the studies used cases from 16 countries only, mainly from Europe (38%), North America (35%) and Asia (15%). We suspect that the priorities of the EU Horizon 2020 programme for research and innovation in NBS-related topics have contributed to this pattern. We also found that, in Europe, German cities and regions such as Berlin, Leipzig, the Ruhr area, and Ludwigsburg were the most used cases for GIM research (Connop et al., 2016, Hansen et al., 2019, Wang et al., 2019). After Germany, cities in the UK were the second most dominant cases reported in Europe (Connop et al., 2016, Hansen et al., 2019). In contrast, GIM studies in North America had geographical dispersion without a single primary driver, like the Horizon 2020 programme's case in Europe (Engström et al., 2018, Meerow and Newell, 2017, Tran et al., 2020, Zhang et al., 2019, Zidar et al., 2017a). It is essential to highlight that GIM studies based on cases from the African (6%), and South American continents are still limited, especially when we compare studies that use cases from Europe and North America.

Considering the spatial scale of research, more than 44% of the GIM studies were from the city scale, 26% focused on the region, while 9% addressed the neighbourhood or district scale (Connop et al., 2016, Hansen et al., 2019, Herzog, 2013). For instance, several studies demonstrated the performance of GIs and their multifunctionality based on population sizes between 50 and 200 thousand people for small urban areas and between 200 and 500 thousand people for medium-sized cities (Council Of Europe (2007), Oecd Ilibrary (2014), Tóth and Timpe, 2017).

3.2. Five clusters

A full-text review of the 34 articles identified five thematic clusters based on theme similarity and keywords (Table 3) and we address these in turn below.

3.2.1. Cluster 1: planning methods for multifunctional GI

A total of 45% of the articles discussed planning methods for multifunctional GI and highlighted the importance of multifunctionality measures in urban planning. The study further proposed divergent methods to capture the magnitude of multifunctionality across different GI features and include these measures in the planning methods.

Several studies developed planning methods for GIM through quantitative and spatial approaches. Specifically, there were efforts to introduce indicators to capture the multiple benefits across different GI in urban areas, including ecological indicators (García et al., 2020). For example, García et al. (2020), (Herzog, 2013) included ecological indicators in the analytical framework for UGI planning. These studies used biodiversity-related parameters to protect the presence of various animals, plants, and microorganisms, thereby promoting the multifunctionality of UGI. Biodiversity-related factors in planning the analysis can identify how and to what extent green spaces can simultaneously provide citizens with fresh air, water, and food. These factors act as benchmarks for developing the master plan for cities. Zidar et al. (2017b) developed a decision support framework to plan GI systems to maximize the urban ecosystem services.

Furthermore, several studies have documented the contribution of spatial indicators to help explain the multifunctionality of UGI. For example, Madureira and Andresen (2013) used evidence of local temperature and population proximity in their spatial analysis to examine the multiple benefits of UGI. In the other study, Meerow and Newell

Table 2
Quality assessment of papers included in PRISMA analysis (SAQOR – Systematic Appraisal of Quality in Observational Research (Patel et al., 2018)).

Paper	Sample	Exposure/outcome measures	Distorting influences	Reporting of data	Overall quality
García et al., 2020	Adequate	Adequate	Adequate	Adequate	Adequate
Herzog, 2013	Adequate	Adequate	Adequate	Adequate	Adequate
Meerow & Newell, 2017	Adequate	Adequate	Adequate	Adequate	Adequate
Madureira & Andresen, 2013	Adequate	Adequate	Adequate	Adequate	Adequate
Chen et al., 2022	Adequate	Adequate	Adequate	Adequate	Adequate
Taylor et al., 2021	Adequate	Adequate	Adequate	Adequate	Adequate
Goodspeed et al., 2021	Adequate	Adequate	Adequate	Adequate	Adequate
Hansen et al., 2019	Adequate	Adequate	Adequate	Adequate	Adequate
Lewis et al., 2022	Adequate	Adequate	Adequate	Adequate	Adequate
Meerow, 2020	Adequate	Adequate	Adequate	Adequate	Adequate
Van Zyl et al., 2021	Adequate	Adequate	Adequate	Adequate	Adequate
Zidar et al., 2017b	Adequate	Adequate	Adequate	Adequate	Adequate
Wang and Banzhaf, 2018	Adequate	Adequate	Adequate	Adequate	Adequate
Zulian et al., 2021	Adequate	Adequate	Adequate	Adequate	Adequate
Zhang et al., 2019	Adequate	Adequate	Adequate	Adequate	Adequate
Wang et al., 2019	Adequate	Adequate	Adequate	Adequate	Adequate
Tran et al., 2020	Adequate	Adequate	Adequate	Adequate	Adequate
Hansen & Pauleit, 2014	Adequate	Adequate	Adequate	Adequate	Adequate
Santiago-Ramos & Hurtado-Rodríguez, 2022	Adequate	Adequate	Adequate	Unclear	Moderate
Isola et al., 2022	Adequate	Adequate	Adequate	Adequate	Adequate
Pietsch et al., 2021	Adequate	Adequate	Adequate	Unclear	Moderate
Guadie et al., 2022	Adequate	Adequate	Adequate	Adequate	Adequate
Wang and Banzhaf, 2017	Adequate	Adequate	Adequate	Unclear	Moderate
Zhang et al., 2022	Adequate	Adequate	Adequate	Adequate	Adequate
Lovell & Taylor, 2013	Adequate	Adequate	Adequate	Unclear	Moderate
Connop et al., 2016	Adequate	Adequate	Adequate	Adequate	Adequate
Wang et al., 2021	Adequate	Adequate	Adequate	Adequate	Adequate
Kim & Song, 2019	Adequate	Adequate	Adequate	Adequate	Adequate
Lebrasseur (2022)	Adequate	Adequate	Adequate	Adequate	Adequate
Chamanara & Kazemeini, 2016	Adequate	Adequate	Adequate	Adequate	Adequate
Engström et al., 2018	Adequate	Adequate	Adequate	Adequate	Adequate
Scott et al., 2016	Adequate	Adequate	Adequate	Adequate	Adequate
Rolf et al., 2019	Adequate	Adequate	Adequate	Adequate	Adequate
Tóth & Timpe, 2017	Adequate	Adequate	Adequate	Adequate	Adequate

(2017) proposed a green infrastructure spatial planning (GISP) concept to capture the magnitude of GIM. GISP aims to highlight the multiple benefits of the infrastructure, including stormwater, social vulnerability, green space, air quality, urban heat island amelioration, and landscape connectivity. Furthermore, Goodspeed et al. (2021) introduced planning support systems (PSS), an analytical tool that is quite similar to the GISP model. PSS aims to support urban planners with a spatial measure to identify specific locations with a high degree of multifunctionality for GI. The PSS model is an integrated urban planning framework that combines geographic information system analysis and visualisation. The PSS model is instrumental in assessing the multifunctionality of rural parks and conservation areas. In conclusion, GISP and PSS seem promising to capture the techniques needed for UGI, despite a limited range of functions and multifunctionality. These two models utilised knowledge on spatial planning to detect the amount of the multifunctionality across certain infrastructures.

Two studies identified that compact and shrinking cities appear to be a driver for aiming the potential of GI to deliver multiple functions in planning (Hansen et al., 2019, Lewis et al., 2022). However, Meerow (2020) argued that politics play an important role in GI planning and in the practices of which areas have priority implementation. Multifunctionality achieved through green infrastructure planning should inform urban planning practices to promote the integration of ecological considerations (Van Zyl et al., 2021). Different from the rest of the studies, Zulian et al. (2021) focused on the policy levels to influence the planning process for GI. The study adopts a functional connectivity index as an instrument to plan multifunctional GI (Zhang et al., 2019).

3.2.2. Cluster 2: approaches to assess GIM

A total of 27% of the articles discussed possible approaches to assess GIM. These papers demonstrate different assessment approaches in estimating the multifunctionality of UGI from socio-ecological angle (Hansen and Pauleit, 2014). Human health relates to the benefits for humans concerning physical and mental health. Finally, socioeconomics refers to subjective satisfaction and well-being benefits and economic factors such as operation and maintenance costs due to UGI.

The ecology, human, and socio-economic parameters have often been combined in spatial analyses to assess GIM performance. For example, Wang et al. (2019) introduced Getis Ord G_i statistics to visualise hot (high value) and cold spots (low value) of multifunctionality within GI. Tran et al. (2020) proposed a method, green infrastructure space and traits (GIST), to identify the highest magnitude of GIM that can be achieved based on the spatial location of the GI and selected plant species that exist in the green spaces. Interestingly, the GIST method helps capture the inequality of the spatial distribution of GI and how the inequality contributes to GIM. The multifunctionality can relate to stormwater diversion, heat island mediation, crime reduction, improved air quality, and biodiversity equity. Pietsch et al. (2021) developed a framework for assessment based on the ESS of recreation, climate regulation and habitat provisioning. An only example from the global South arises the need for assessment framework of multifunctional GI as contribute to the environmental and socioeconomic values of the city residents (Guadie et al., 2022). Remote Sensing (RS) mapping tools allow measuring and assessing urban GI at more detailed resolutions. RS tools pay tribute to GI multifunctionality by making it possible to assess the urban green component according to different kinds of GI functions (Wang and Banzhaf, 2017). Based on the three dimensions of economy, society, and ecology, the multi-functional value of green infrastructure can be measured more accurately to provide a reference for international counterparts engaged in related research. A comprehensive evaluation index system for the three functions of green infrastructure: economy, society, and ecology (Zhang et al., 2022). It is important to note also that the aforementioned researches on the assessment approaches of GIM often conduct the analysis based on three different

Table 3
Description of five thematic clusters identified by a full-text screening of papers included in the review.

Cluster	Description	Keywords	Definition	Resources
1	Planning methods for Multifunctional GI	Planning, land use, master plan, green infrastructure, nature-based solutions, multifunctionality	Methods and approaches to decode and decipher the most effective ways to plan GI multifunctionality.	(García et al., 2020) (Herzog, 2013) (Meerow & Newell, 2017) (Madureira & Andresen, 2013) (Chen et al., 2022) (Taylor et al., 2021) (Goodspeed et al., 2021) ((Hansen et al., 2019) (Lewis et al., 2022) (Meerow, 2020) (Van Zyl et al., 2021) (Zidar et al., 2017b) (Wang and Banzhaf, 2018) (Zulian et al., 2021) (Zhang et al., 2019)
2	Approaches to assess GIM	Assessment, measurement, evaluation, multifunctionality	Methods to evaluate the multifunctionality of GI	(Wang et al., 2019) (Tran et al., 2020) (Hansen & Pauleit, 2014) (Santiago-Ramos & Hurtado-Rodríguez, 2022) (Isola et al., 2022) (Pietsch et al., 2021) (Guadie et al., 2022) (Wang and Banzhaf, 2017) (Zhang et al., 2022)
3	Benefits of multifunctionality	Ecosystem services, ecosystem benefits, ecology, multifunctionality	Benefits for humans that are derived directly or indirectly from nature	(Lovell & Taylor, 2013) (Connop et al., 2016) (Wang et al., 2021a) (Kim & Song, 2019) (Lebrasseur (2022))
4	Sustainability and climate adaptation	Sustainability, climate change, mitigation, adaptation	Enhancing the GI multifunctionality as a sustainable solution	(Chamanara & Kazemeini, 2016) (Engström et al., 2018) (Scott et al., 2016))
5	Urban agriculture	Food production, and agricultural landscapes	Cultivating, processing, and distributing food around urban or peri-urban areas	(Rolf et al., 2019) (Tóth & Timpe, 2017)

urban scales (city region, neighbourhood, and site block). However, only one study had focused the analysis on assessing the multifunctionality in the regional scale (Isola et al., 2022).

3.2.3. *Cluster 3: benefits of multifunctionality*

Five papers addressed the role of GIM in contributing to the number of benefits for ecosystem services (ESS). The challenge is that the distinction between ESS and ecosystem functions is not always well-described in these papers, making it difficult to assess the exact benefits. Nevertheless, according to (Lovell and Taylor, 2013), the benefits related to ESS strongly link to landscape-related components, such as treed lawn and community gardens. Wang et al. (2021) tried to bridge the landscape ecological science with the urban planning based on the ESS targeting to improve GI multifunctionality. Past studies report that ecological, hydrological, recreational, working lands and community components are vital for the benefit scores. Some studies use ES mapping tools to assess the benefit scores of GIM for ESS. The studies, in particular, focused on landscape-related components to visualise the GIM benefits for ESS (Lebrasseur (2022)). In the other studies, a cost-benefit analysis is included to assess ESS (Connop et al., 2016, Kim and Song, 2019). However, understanding ecosystem services and functions is often inconsistent across studies. We also found that several studies investigate the multiple benefits of ESS, but the synergies and the trade-offs across ESS elements to form the benefit scores are still unclear.

3.2.4. *Cluster 4: sustainability and climate adaptation*

Three papers addressed the contribution of GIM to urban sustainability and climate adaptation (Chamanara and Kazemeini, 2016, Engström et al., 2018). The studies have revealed that the sustainability and climate change adaptation impacts gained through GI adoption strongly associate with ecosystem services, providing benefits in water management, energy use, and carbon emissions (Engström et al., 2018). Problematic areas like brownfields act as potential multifunctional green spaces that can contribute to climate adaptation (Scott et al., 2016). Similarly, in the other study, incorporating multifunctional landscapes in urban design is vital for the natural ecosystem, thereby contributing to sustainability and climate change (Chamanara and Kazemeini, 2016). Using the case of watercourses in Tehran, the study demonstrates the ability of multifunctional landscapes to maintain vital ecological processes and services and to protect the health and biodiversity of wildlife populations.

3.2.5. *Cluster 5: urban agriculture*

Urban agriculture was the fifth cluster associated with GIM research, mainly discussing cultivating, processing, and distributing food around urban or peri-urban areas (Rolf et al., 2019, Tóth and Timpe, 2017). In Europe, urban agriculture was part of urban activities and social movements for sustainable communities to ensure food security, nutrition, and income generation. Urban agriculture is necessary to produce fresh vegetables, fruits, and meat products, social inclusion (Sanesi et al., 2017), and entrepreneurship (Rolf et al., 2019, Tóth and Timpe, 2017).

It has been reported that land sharing, shared food production, and agricultural landscapes have multifunctional benefits for urban agriculture, such as natural pest control (Rolf et al., 2019) and service provisioning in the landscape (Tóth and Timpe, 2017). Stakeholders identified two main strategic aspects to assist in multifunctionality: highly productive and less-productive farmland (Rolf et al., 2019). In summary, the studies report that urban agriculture contributes to the multifunctionality of several landscape scales, offering multi-benefits to society if appropriately managed. However, since the functions depend on the underlying conditions and landscape parameters, verifying synergies and trade-offs with other functions is necessary to target GIM in urban agriculture.

3.3. Network analysis across the five clusters

The network analysis reported the relationships among the five clusters based on thematic similarity across papers (Fig. 2). The results showed that the three clusters of assessment, planning, and benefits of multifunctionality are well connected (Fig. 2). In particular, the analysis found that the assessment approaches of GI strongly connect with the planning methods and the benefits of UGI. These results reflect that the planning for UGI often depends on assessing the different functions attached to each GI (Madureira and Andresen, 2013). A study from Detroit seems to confirm this interpretation (Meerow and Newell, 2017), showing that the proposed plan for GI can be effectively implemented if the assessment regarding the multifunctionality measures of GI is first conducted. Thus, the assessment results will be the basis for UGI planning. Furthermore, a strong linkage between benefits and assessment was observed. These findings indicate that the benefit scores obtained from ESS are strongly influenced by the results of the GIM assessment and the way of GIM is assessed.

As expected, papers on the benefits of multifunctionality were linked to the four other clusters. Most of them explained multifunctionality while trying to measure it based on the benefits that GIs can offer. The papers further reveal that the linkage between ESS and benefits and planning was powerful because ESS and benefits were integrated into the GI planning process (Zidar et al., 2017a). It shows that ESS provides various benefits to humans through their natural and healthy environment. The benefits can be related to the natural pollination of crops, clean air, water, extreme weather mitigation, and human well-being. Evidence has revealed that ESS can serve as the land use and environmental planning framework to understand the trade-offs between land use and built environment development scenarios. ESS also connects with ecological risk assessment, in which an ES-based framework can be used to evaluate and maximise the multifunctionality of GI (Madureira and Andresen, 2013, Meerow and Newell, 2017, Zidar et al., 2017a). In addition, ESS has been substantial in uncovering sustainability and climate change challenges (Chamanara and Kazemeini, 2016) and urban agriculture (Tóth and Timpe, 2017).

The cluster of urban agriculture was underrepresented in the literature on multifunctionality. This evidence contributes to limited knowledge of how and to what extent the urban agriculture associates with the other clusters. Urban agriculture—and more specifically, agriculture in the rural areas that are located within a city limit—has been in danger over the past decade because of the challenges of climate change and growing urbanisation. Urban agriculture has played a crucial role in spatial development because it provides food for people and is a habitat for species, and a place with unique and special physiognomy. It is therefore suspected that urban agriculture is critical to urban planning and approaches to target sustainability and climate change adaption. However, this argument needs to be validated through future research that focuses on the GIM in the context of urban agriculture.

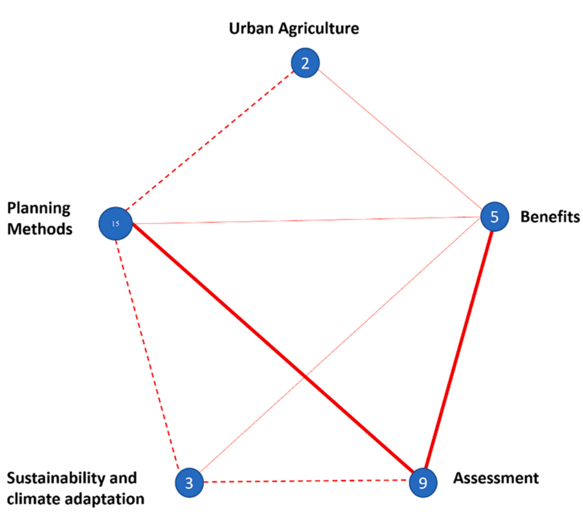

Fig. 2. Linkages among the five clusters identified in a full-text screening of papers on urban green infrastructure multifunctionality. Line thickness demonstrates the magnitude of linkages.

4. Discussion: planning for UGI, the multifunctionality concept, and the knowledge gap

Past studies have suggested the critical correlation between the multifunctionality concept in UGI and spatial and ecological planning. The results have illustrated the role of spatial planning and ecology science in exploring the synergies and trade-offs between the available functions and benefits that exist in urban infrastructures (García et al., 2020, Salata and Grillenzoni, 2021). In particular, spatial planning help map multiple functions across geographical zones, while ecological planning can indicate the magnitude of nature conservation and biodiversity of different GI features. Spatial planning and ecology science tools can assess the current situation and identify the areas for improvement to target the multifunctionality of UGI.

Nevertheless, our analysis found two critical knowledge gaps in the current literature concerning spatial and ecological planning for GIM. The first knowledge gap was regarding limited evidence of systematic methodologies to quantify multifunctionality based on urban spatial planning considerations. Our analysis found only two methodological review studies on spatial planning for GIM. First, the study by Madureira and Andresen (2013) introduced the spatial priority areas for UGI planning and development. The study argued that spatial priority areas could indicate how to improve local temperature regulation and predict reasonable population proximity to different categories of urban green spaces. The study suggested two parameters for assessing UGI functions: 1) local temperature regulation by the given green areas and 2) population proximity to public green spaces. Urban planners and policymakers can use the method to identify spatial synergies and conflicts between spatial priorities. The method can further identify the relevant spatial policies for different UGIs, and the procedures to adapt to each infrastructure function.

The second method is Green Infrastructure Spatial Planning or GISP (Meerow and Newell (2017)). GISP provides a stakeholder-based methodology for measuring GI trade-offs, synergies, and hotspots. The model can support spatial planning at the city scale by making assessments at more minor spatial scales. The GISP adopts a Geographic Information System (GIS) multicriteria approach that integrates six benefits: 1) stormwater management, 2) social vulnerability, 3) green space, 4) air quality, 5) urban heat island amelioration and 6) landscape connectivity (Meerow and Newell, 2017). The analysis uses stakeholder-based feedback to map spatial trade-offs and synergies. The assessment uses the six criteria weighted based on local stakeholders' priorities. The GISP method introduced a technique to plan GI and tested the methods using the US and the Philippines cases under different urban settings. The study concluded that the GISP model was effective as a tool to assess the multifunctionality of GI and help policymakers to design relevant spatial planning strategies.

The challenge, however, is that the results did not always indicate the most suitable areas for GI based on the six benefits because of the complexity arising among the benefits (Meerow and Newell, 2017). For example, the results indicated that the most suitable green space for stormwater management might create challenges for landscape connectivity because the results can contradict the two aspects (stormwater management versus landscape connectivity). The other challenge concerned the justification of the experts. The subjective opinions of the experts lead to inconsistency in how the model weighs the six criteria.

In other recent papers, attempts were made to identify the emergence of planning frameworks that identify the actions and areas for achieving maximum GI multifunctionality (Chen et al., 2022, Wang et al., 2021b). Wang et al. (2021) coupled the ecology field with GI planning to measure the multifunctionality of UGI. The studies used spatial analysis techniques, such as open GIS, to inform urban planners in predicting the patterns of GIM.

The second knowledge gap was regarding the limited parameters for planning UGI with solid multifunctionality. In particular, five parameters miss in the current studies. First is the **GI's spatial distribution and pattern** (Anguluri and Narayanan, 2017, De La Barrera et al., (2016)). Because forecasting the spatial distribution and GI pattern can help guide urbanisation sprawl, the spatial distribution parameters help understand the processes, effects, and ecosystem services operating GI at different spatial scales. For example, the patch size distribution at the landscape level could reveal the equitable distribution of GI linked to social justice because this parameter capture the accessibility of citizens to GI (Weng, 2007). The spatial distribution of GI can also indicate its spatial heterogeneity and catchment function (Demuzere et al., 2014).

Second is the **optimal distance** between the GI and the home locations (Poelmann, 2020). Past studies have indicated that multifunctionality can be better attained if the distance between green spaces and home is relatively short. Suppose the distance matters for promoting GI to citizens, making GI more multifunctional. In that case, the question is, what is the optimal distance between GI and home to make UGI more multifunctional? Therefore, knowledge related to the optimal distance helps policymakers and practitioners plan and develop GI. In Norway, the suggested distance to reach GI from home is between 300 and 500 m for small- and medium-scale cities (The Norwegian Ministry Of Local Government And Modernisation (2019)). However, this range is difficult to adopt in the US because of geographical constraints and population density. In some studies, a public park should be accessible around a five-minute walk (approximately 0.2 miles or 0.32 km) for physical health reasons. However, in other studies, it was suggested that the optimal distance is between 0.5 miles (0,8 km) and 0.75 miles (1.2 km) (Blanck et al., 2012, Browning and Lee, 2017). Therefore, we suggest that using a parameter to indicate the optimal distance to reach GI from home would help urban planners and public health officials plan UGI that attach to the citizens.

Third is the **integrated network** among the different GIs. Because the characteristics of GI units differ, it is crucial to explore how a GI connects to the other GIs that provide more significant homogenous or heterogeneous service landscapes. It is also essential to assess whether a GI can only connect to another that is the same type or if it is likely to connect with the other types of GI (Ignatieva et al., 2011, Jim and Chen, 2003, Kong et al., 2010, Li et al., 2005, The Norwegian Ministry Of Local Government And Modernisation (2019)). For example, a green park can connect well with other green parks and structures for stormwater management. However, a green roof does not always connect to another roof; instead, it connects well with green facades in the given built environment.

Fourth is the **accessibility** to reach GI (Dadvand et al., 2015, Ekkel, De Vries (2017), The Norwegian Ministry Of Local Government And Modernisation (2019), Van Herzele and Wiedemann, 2003, World Health Organisation, 2017). According to past studies, an accessible infrastructure can enable citizens to visit the infrastructure more regularly. The mode of transport, travel distance, and time can influence this accessibility factor. For example, people will likely visit green parks if the location is accessible by different modes of transport and within an acceptable distance. It is essential to note that people prefer to reach green areas if they are close to the main roads.

Fifth is **public participation and engagement** using GI (Byrne and Sipe, 2010, Fors et al., 2015, Ives et al., 2014, Rall et al., 2019, Rosol, 2010). Because GI is designed and developed for citizens, capturing how people think and react to given infrastructures has been found to be necessary. Public participation in GI should be provided based on local needs (Ives et al., 2014). Children and the aging population are two user groups GI should consider when planning, assessing, and targeting better spaces. Interaction with nature is vital to children's brain development (Kahn Jr and Kellert, 2002, Kellert, 2012). They are arenas for play, exploration, and education. In recent years, the aspect of child-friendly green spaces has attracted the attention of researchers, stakeholders, and policymakers. Some studies have reported the importance of green spaces for children, making green spaces a critical indicator of child-friendly cities. Green spaces consist of meeting and gathering places for older people and places for relaxation. Thus, the design of green spaces is the most crucial parameter for older people (Arnberger et al., 2017). GI is essential to an age-friendly urban environment, providing several health benefits, particularly for older people (Kabisch et al., 2017, O'brien (2014)).

5. Conclusion

As cities strive to provide high-quality green areas locally to residents, UGI with a high degree of multifunctionality is crucial in making cities more sustainable and liveable. The multifunctionality in UGI help explain the multiple benefits offered to citizens related to social, economic, and environmental aspects. However, despite the importance of the multifunctionality concept in UGI, we found that most of the papers we reviewed only considered a limited number of aspects of function rather than multiple functions. Since limited methods and indicators to assess the performance of GIM in research, the multifunctionality assessment is a difficult task. We further found vague concepts concerning the functions and benefits of GIM in some studies. In particular, some studies did not distinguish clearly between functions and service. Such differences lead to the use of diverse methods to explain GI multifunctionality.

Our analysis reported five theme clusters underlying past studies dealing with GIM: 1) planning methods, 2) assessment approaches, 3) ecosystem services and benefits, 4) sustainability and climate adaptation, and 5) urban agriculture. A network analysis was conducted to map the relations and similarities among the five clusters. The results found some connections exist across the clusters. The most noticeable result is that there are obvious connections between the benefits of multifunctionality and the planning methods, the assessment approaches, the sustainability and climate change topic, and the urban agriculture clusters.

This study has captured some concepts of multifunctionality to UGI in past studies. We also found some studies introducing planning methods and assessment approaches to examine GIM. However, limited studies have offered a comprehensive framework with multiple assessment indicators of function, benefit, and service to examine the performance of UGI. Nevertheless, we understand that assessing GI functions is a difficult task. We also know that it is unclear how to use one overall measurement encompassing all the distinct functions of GI. Therefore, future research should seek suitable approaches for assessing the trade-offs and synergies among functions in a robust yet straightforward manner. The approach can calculate the functional benefits under different functions, such as the role of green roofs in stormwater management, climate change mitigation, and carbon storage. At the same time, these methods should be placed under the spatial and ecological planning context.

Finally, we recommend that future efforts need to provide a comprehensive assessment using qualitative and quantitative measures and consider ecological, social sciences, and economic benefits. It is an analytical framework to measure the performance of UGI. This framework will be valuable for policymakers and urban planning practitioners as an instrument in urban planning. It will help urban planners effectively develop an urban infrastructure plan that considers green and multifunctionality aspects.

CRediT authorship contribution statement

Maria Korkou: Conceptualization, Methodology, Data curation, Visualization, Writing – original draft, Writing – review & editing. **Ari K.**

M. Tarigan: Conceptualization, Writing – review & editing, Supervision, Project administration. **Hans-Martin Hanslin:** Conceptualization, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article, and we have fully respected the research ethics principles.

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