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An Exploratory Case-Study Approach to Understand Multifunctionality in Urban Green Infrastructure Planning in a South African Context

*Burne Van Zyl[1], Louis G. Lategan[1], Elizelle J. Cilliers[1,2] and Sarel S. Cilliers[1]**

[1] Unit for Environmental Sciences and Management, North West University, Potchefstroom, South Africa, [2] School of Built Environment, University of Technology Sydney, Sydney, NSW, Australia

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****Correspondence:***
Sarel S. Cilliers
Sarel.Cilliers@nwu.ac.za

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The United Nations Sustainable Development Goals (SDGs) intend to encourage liveable urban environments by 2030 with a main focus on strategies to achieve environmental and human well-being. In the same way, the multifunctionality principle of green infrastructure planning aims to develop and protect urban green spaces to provide several ecosystem services to increase human well-being whilst protecting the environment. With this in mind, this paper seeks to gather evidence on the nexus between multifunctionality and green infrastructure planning to achieve the SDGs within a South African context. The implementation of green infrastructure to this effect depends on creating awareness of different typologies of green infrastructure elements and the ecosystem services they provide to strengthen the implementation of the green infrastructure concept in urban planning practice. Within the aim of context-specific considerations to green infrastructure planning, green infrastructure typologies possible for implementation within a South Africa urban planning practice context are considerably more limited. A qualitative research approach is employed using case studies identifying specific examples to explore South African green infrastructure typologies and their multifunctionality. Different multifunctionality concepts are recognized by urban planners in South Africa. The research findings highlighted that multifunctionality achieved through green infrastructure planning should inform urban planning practice to promote the integration of ecological considerations. The paper ultimately provides a deeper insight into the expanding field of green infrastructure research in a South African context by underlining context-based multifunctional green infrastructure typologies and accordingly emphasizes, mainstreaming the ecosystem services concept as part of urban planning practice to address the SDGs locally.

Keywords: urban green infrastructure typologies, urban planning, urban ecology, ecosystem services, multifunctionality

INTRODUCTION

Urbanization is regarded as the 21st century's most transformative force, intensifying social, economic, and environmental demands (Watson, 2016). Mounting evidence suggests that human activity within and outside human settlements (Maes et al., 2019) is causing global environmental change, thrusting the world into a new geological epoch, the Anthropocene (Griggs et al., 2013). The pressures caused by human activities risk extensive, unexpected, and potentially irreversible changes to basic earth-system processes as planetary boundaries are pushed to the limits. These cause risks at global and local scales including climate change; terrestrial and marine biodiversity loss; interference with the nitrogen and phosphorus cycles; stratospheric ozone depletion; ocean acidification; global freshwater shortages; chemical pollution and atmospheric aerosol loading (e.g., Griggs et al., 2013; Ahmed and Puppim de Oliveira, 2017; Maes et al., 2019). Growing environmental awareness and concerns as a result of such risks birthed the notion of sustainable development (Hák et al., 2016) which has evolved through different iterations, based on the fundamental premise of a more balanced approach to economic, social and environmental development (Lategan, 2017). There is international consensus that cities will increasingly present the loci where battles for sustainable development will be waged (Klopp and Petretta, 2017).

In recognition, the United Nations (UN) has increased its focus on urban areas, from cities as platforms, to cities as vectors for change (Watson, 2016). Whereas the Millennium Development Goals (MDGs) (2000–2015), provided eight broad goals to guide more sustainable development approaches and presented an urban dimension, cities were largely neglected (Klopp and Petretta, 2017). A stronger focus on cities emerged in the 17 Sustainable Development Goals (SDGs) released by the UN in 2016 as part of the 2030 Agenda for Sustainable Development (Valencia et al., 2019). The 17 SDGs extended the MDGs, but placed a more profound emphasis on the links between the economic, social and environmental aspects of sustainability (Stafford-Smith et al., 2017). Each SDG is accompanied by several targets and indicators (Valencia et al., 2019). An independent urban goal was included as SDG 11, to "Make cities and human settlements inclusive, safe, resilient, and sustainable," supported by ten specific targets (United Nations, 2021).

Alternative greener development approaches may hold substantial promise for more sustainable urban development in fulfillment of multiple targets set under SDG 11. An area of increasing research interest is the application of nature-based solutions to complement and/or replace traditional urban development instruments in this regard. As such, green infrastructure (GI), also termed sustainable infrastructure (Chatzimentor et al., 2020), is now a major transdisciplinary research theme that transects geography, ecology and urban planning (Benton-Short et al., 2019). Despite its prevalence, the GI concept remains contested (Benedict and McMahon, 2006, p. 1; Davies et al., 2006), often being context-based and defined (Benedict and McMahon, 2006, p. 1; Wright, 2011, p. 1007). We define GI as: "An interconnected network within an urban area, consisting of a broad range of environmental features (including all natural, semi-natural, and man-made green and blue spaces) planned, designed, and managed to conserve ecosystem functions, contributing to biodiversity conservation and providing social, economic, and health benefits to humans by delivering multiple ecosystem services" (Benedict and McMahon, 2006; Cilliers and Cilliers, 2016). The delivery of these potential benefits, as ecosystem services (ES) (see section Ecosystem Services Delivered By Green Infrastructure), is facilitated by the multifunctionality that GI can provide through its varied constituent environmental features, or elements (Hansen et al., 2019). Multifunctionality, as a core feature of GI, can serve various objectives across the urban-rural divide, administrative scales and policy sectors (Chatzimentor et al., 2020). Accordingly, support for ecosystem-based approaches is not limited to the targets set for SDG 11, but cuts across multiple spheres. For example, Maes et al. (2019) investigated the normative implications of all 169 targets for their interlinkages with urban ecosystems, finding that 54% of targets called for action in relation thereto. Despite its potential, the concept of GI multifunctionality remains elusive and poorly conceived (Hansen et al., 2019).

Research on GI has historically been localized in the Global North (developed countries), but academic publications on the subject from the Global South (developing countries) have seen a steady increase (Pauleit et al., 2021). South African-based research has been specifically prolific (Du Toit et al., 2018). South Africa (SA), a signatory of the SDGs, has presented several case studies on different aspects of urban GI and more sustainable planning approaches focused on major cities like Cape Town (Taylor, 2016), Durban (Roberts et al., 2012) and Johannesburg (Bobbins and Culwick, 2015) and on smaller urban areas in the Eastern Cape (e.g., Shackleton et al., 2018) and North-West provinces (e.g., Cilliers et al., 2018). This does not imply that green planning or GI is a standard approach to development or even that it is widely applied in SA. Multiple studies have commented on the lack of priority given to ecological issues in studies focussed on urban SA, as in other developing nations (Lategan and Cilliers, 2014; Cilliers, 2019, p. 455), where greenery is considered a mere luxury (Combrinck et al., 2020). Pasquini and Enqvist (2019, p. 9) relate such perceptions to a potential lack of ecological literacy. Huston (2018, p. 135) found that the limited current implementation of GI in SA can be traced to misconceptions and a lack of GI education that has led to insufficient know-how and knowledge of implementation possibilities amongst South African urban planners. Specific mention is made of a lack of knowledge on GI typologies (Cilliers and Cilliers, 2016, p. 11), as different green space categories (or GI elements), and their multifunctionality to deliver ES (Hansen et al., 2017, p. 31) that prohibit broader practical application. In a study of South African planners, Van Zyl et al. (in press) confirmed a narrow conceptualization of multifunctionality amongst planning practitioners in this regard (see section Multifunctionality as a Multifaceted Concept for an elaboration).

This paper aims to provide evidence on the nexus between multifunctionality and GI within a South African context by delivering a preliminary framework of GI typologies and their potential ES to mainstream multifunctionality through GI in urban planning. Based on the preliminary points of departure provided in the introduction and in support of this aim, section Ecosystem Services Delivered By Green Infrastructure discusses the ES concept as an integral component of GI to highlight the multiple benefits potentially provided. In section Green Space Typologies as Green Infrastructure Elements a synopsis of GI elements as a typology inventory is presented that may deliver a variety of ES. In section Multifunctionality as a Multifaceted Concept, multifunctionality is discussed in more detail, discussing interpretations of the concept as part of GI and urban planning and its connection to sustainable development. The Introduction and sections Ecosystem Services Delivered By Green Infrastructure, Green Space Typologies as Green Infrastructure Elements, and Multifunctionality as a Multifaceted Concept inform the last sections in which a qualitative approach is followed to analyze South African case studies as examples of GI applications through various GI elements, which are then ranked from mono- to multi-functional. The last section provides South African urban planning practice with a preliminary framework comprised of examples of South African GI elements and the possible ES generated by these elements, along with the level of multifunctionality of each element to inform planning decision-making and mainstream multifunctionality through GI in urban planning. Results are further utilized to conclude on the connection between the ecological aspects and concepts of GI planning, ES, and multifunctionality.

ECOSYSTEM SERVICES DELIVERED BY GREEN INFRASTRUCTURE

Several definitions for ES have been developed in different disciplines (Cilliers et al., 2013, p. 682). An uncontroversial and universally agreed upon definition is yet to emerge (Grunewald and Bastian, 2015, p. 11). However, we synthesize ES as: "the benefits all living species (especially humans) derive, directly or indirectly, from the capacity (function) of ecosystems to provide goods and services that satisfy needs (Bolund and Hunhammar, 1999, p. 297; De Groot et al., 2010, p. 260). ES have been classified according to four categories, namely provisioning, regulating, cultural, and habitat/supporting services (TEEB, 2010; La Notte et al., 2017, p. 392).

Provisioning ES refer to the capability of natural (e.g., rivers, biomes) or semi-natural (e.g., community gardens) green spaces to contribute physical products, materials or goods consumed directly by humans (Hein et al., 2006, p. 62; Haines-Young and Potschin, 2010, p. 111; Grunewald et al., 2018, p. 13). These include food, fresh water, energy, raw materials, and medicinal plants (Hein et al., 2006, p. 62; TEEB, 2010, p. 3; Shackleton et al., 2021, p. 206). Research suggests that residents in cities of the Global South rely more on locally sourced provisioning ES than those residing in the global North, thus necessitating a more secure local supply of these ES, inter alia by providing sufficient and equitable distribution of urban GI (Shackleton et al., 2021, p. 217-219). Regulating ES include the services provided by ecosystem functions (Andersson et al., 2016, p. 446) like regulating the climate, the removal of pollutants by air and water filtration, seed dispersal and pollination, water storage, filtration, and drainage, protection from disasters such as landslides and storms or providing pest and human disease regulation (TEEB, 2010, p. 3; Colding, 2011, p. 229; Gómez-Baggethun and Barton, 2013, p. 178). Seeing that regulating services mostly indirectly benefit humans, these services are often less obvious to the general public (Langemeyer, 2015, p. 45). Most of the research on urban regulating ES emanates from the Global North, leading Escobedo (2021) to caution against policy formation based on principles that neglect the local contexts of the Global South's unique socio-economic conditions. Cultural ES are classified as the non-material benefits humans obtain from ecosystems that meet cultural or spiritual needs (Haines-Young and Potschin, 2010, p. 111) obtained when visiting a green space, living in a green environment or simply having access to views of green areas (Hein et al., 2006; Sharmin, 2020). The demand for cultural ES is not homogeneous as it is intrinsically linked to socio-economic profiles, needs, experiences, values and behavior (Hein et al., 2006; Wilkerson et al., 2018, p. 103; Charoenkit and Piyathamrongchai, 2019, p. 1). Examples of cultural ES include cognitive development, recreation, aesthetic experiences, spiritual enrichment and tourism opportunities, providing support to knowledge systems, accommodating social group gatherings and sense of community (Gómez-Baggethun and Barton, 2013, p. 239; Molla, 2015, p. 37). Dobbs et al., 2021, p. 258) emphasize a lack of research on cultural ES in cities of the Global South that present differences in terms of the "proportion of indigenous communities, urbanization dynamics, and environmental inequities" that require "context-specific information, instruments, or guidelines" to guide planning decisions. According to Haines-Young and Potschin (2010, p. 111) habitat services (or supporting services) do not directly benefit humans (Liquete et al., 2016, p. 250), but are necessary to facilitate the fulfillment of all other ES. Examples include the provision of natural habitats (De Groot et al., 2002, p. 396) that accommodate genetic diversity (TEEB, 2010, p. 3). Accordingly, ES are provided by the ecosystems accommodated in certain green and blue land uses that constitute important elements of GI as interconnected nodes and links (Burton and Rogerson, 2017). The following section explores the concept of green spaces as GI elements and the typologies devised in the literature.

GREEN SPACE TYPOLOGIES AS GREEN INFRASTRUCTURE ELEMENTS

Whilst an abundance of studies have defined GI, there are significantly fewer examples that have provided classifications of GI elements (Koc et al., 2017, p. 15). In terms of definitions and scope, green space may be used interchangeably with terms such as green environments, urban green spaces or open spaces to include multiple types of spaces as GI elements. For example, natural green spaces that serve as green reservations such as national wildlife parks and sanctuaries. Definitions often include formal or "developed" public spaces that include "hard surface" civic spaces like squares, playgrounds, public plazas, and paved areas (Dunnett et al., 2002, p. 8) with elements of soft vegetation cover (Schäffler and Swilling, 2013, p. 247; Papageorgiou and Gemenetzi, 2018, p. 86). Anthropogenically developed green areas may also be included as constituents of other urban land uses (Shackleton et al., 2018, p. 273), including parks, golf courses, botanical gardens, street trees, school grounds, and sports fields (McConnachie and Shackleton, 2010, p. 250; Schäffler and Swilling, 2013, p. 247) often primarily developed for their recreational characteristics and secondarily for their positive environmental contributions (Grunewald et al., 2018, p. 26). Several additional examples have been recognized. These include informal or undeveloped spaces, often as the remnants of existing pristine natural areas (Planchuelo et al., 2020, p. 1) or fragmented patches of natural habitats; and community and domestic gardens (Cameron et al., 2012, p. 129; Cilliers et al., 2018), in recognition of their significant contributions to urban greenery and ES (Shackleton et al., 2018). GI also includes all areas used for urban agricultural practices such as the cultivation of plants for food and the production of livestock (Drescher et al., 2021, Steenkamp et al., 2021); as well as other gray-green elements that combine vegetation with engineered technical structures or gray infrastructure (Pauleit et al., 2011, p. 272) such as green roofs, green walls; rain gardens, bioswales, or constructed wetlands (Mell, 2013, p. 153; Hansen et al., 2017, p. 9). It must be noted that several of these typologies may overlap depending on the design and use of a space and that certain elements may provide fewer or more ES.

No universal typology for green space exists as no single typology could account for diverging natural conditions (geomorphological, climatic, and biological), historical backgrounds, and social demands linked to different contexts (Cvejić et al., 2015, p. 9, p. 10; Koc et al., 2017, p. 32). Several attempts have been made to further refine green space typologies internationally and in SA based on the definitions and scope discussed. Prominent examples base classifications on scale (The Scottish Government, 2011; Cvejić et al., 2015); function (Dunnett et al., 2002; Benedict and McMahon, 2006; Davies et al., 2006; Stiles, 2009; Council for Scientific Industrial Research (CSIR), 2019); land cover (Mell, 2010; Schäffler et al., 2013); location and form (City of Tshwane., 2005; Cvejić et al., 2015); GI components (Koc et al., 2017); and as either formal or informal (Rupprecht and Byrne, 2014). Whilst discussing these individual approaches falls beyond the limits of this paper, **Table 1** draws on these sources to provide a broad overview of main typologies as a preliminary inventory of GI elements (first three columns). The terms GI elements and green spaces or open spaces are used interchangeably in the table depending on use in the literature consulted.

A review of the typologies captured in the first three columns of **Table 1** underlines the multifaceted nature of green spaces in urban areas and alludes to the potential for these elements to accommodate multi-functional uses to fulfill economic, social, and environmental needs. Section Multifunctionality as a Multifaceted Concept discusses multifunctionality as a concept in this regard and focusses on interpretations of the concept as part of GI and urban planning and highlights links to sustainable development.

MULTIFUNCTIONALITY AS A MULTIFACETED CONCEPT

Multifunctionality has been methodically and theoretically developed as a constituent of multiple concepts and within multiple disciplines (Van Zyl et al., in press). The principle constitutes a key feature of GI through which it references the integration or combination of different functions within a GI element that enhances the delivery of multiple economic, social, and environmental benefits (Pauleit et al., 2011; Lennon et al., 2016; Hansen et al., 2017), or ES (Hansen et al., 2019, p. 100). In urban planning, four dimensions have come to define the concept. These are (1) multifunctionality through space based on horizontal or vertical interconnection of different functions within a space (spatial coverage); (2) multifunctionality through usage to provide several activities and functions for humans and other living beings to deliver on various needs; (3) multifunctionality through the ability to provide different functions at different times; and (4) multifunctionality based on the variety of services provided by the space in service of economic, social, and environmental requirements (Živković et al., 2019, p. 206). Obvious synergies between interpretations of multifunctionality as part of GI and within the field of urban planning are thus obvious, highlighted by contributions to more sustainable development trajectories in which urban areas interact as social-ecological systems (Hansen and Pauleit, 2014, p. 525). **Table 2** is a summary of the benefits of multifunctionality in relation to the three aspects of sustainability to further underscore these synergies and the inclusion of multifunctionality as a core development consideration.

Whilst multifunctionality has been defined in urban planning according to the four dimensions provided above and recognized for its contributions to sustainability (Wei, 2017, p. 4), as encapsulated in **Table 2**, the principle is often overlooked by urban planners (Hansen et al., 2017, p. 43; Di Marino et al., 2019, p. 644;) or applied to a limited extent in the combination of several socio-economic, but not necessarily environmental, functions in the same area (Rodenburg and Nijkamp, 2004, p. 274; Di Marino et al., 2019, p. 644). Van Zyl et al. (in press) conducted a quantitative investigation of South African planners based on a digital survey of their conceptualization of multifunctionality in the practice of planning. Respondents could select a definition for multifunctionality based on three interpretations. Firstly, multifunctionality as an urban land use concept, referring to the spatial arrangement and concentration of mono-functional elements in the landscape. Secondly, multifunctionality, as the combination of several land uses to provide more than one activity or socio-economic function in the same space within a landscape. Thirdly, multifunctionality as a GI

TABLE 1 | A GI typology inventory and selected case studies with examples of specific GI elements.

		GI element	Case-study	Sources
Gray-green designed elements	Green roof	A vegetated landscape installed on a roof surface using soil and plants in place of traditional roof material	eThekwini Municipality Green Roof Pilot Project; The Priority Zone rooftop garden (Durban, KwaZulu-Natal)	(eThekwini Municipality., 2011, p. 11; Priority Zone Durban, 2013; Pillay, 2017)
	Green wall	A vertical vegetated surface (e.g., facades, walls, blind walls, and partition walls)	The "Veld wall" (Rosebank, Johannesburg, Gauteng)	(Knoll, 2018, p. 29; Pro Landscaper Africa, 2018, p. 37)
	Sustainable urban drainage systems (constructed wetland)	Man-made wetlands replicating natural processes (e.g., water purification and waste-water treatment) of natural wetlands. Resemble natural wetlands, composed of plants, substrate, and microorganisms	Intaka Island constructed wetland (Cape Town, Western Cape)	(University of Cape Town., 2004; Planning Partners, 2005; Wynne-Jones, 2005; Mallett, 2017)
	Sustainable urban drainage systems (rain gardens and bioswales)	Rain gardens are typically lowered landscaped garden beds that collect rainwater from proximate hard surfaces and store the water for a period in the rain garden basin, so it slowly infiltrates back into the soil. Bioswales are engineered multilayered trenches with vegetation (water runoff conveyance systems) along streets and parking areas. In both rain gardens and bioswales pollutants are removed before the storm water infiltrates back into the ground	University of Pretoria rain garden (Pretoria, Gauteng) (see **Supplementary Table 2**)	(Dunstan and Sampson, 2013; Steenberg, 2013)
Urban agriculture	Vertical Farming	The practice of crop cultivation in vertical layers or the integration of crops on a vertical structure (e.g., a building)	The Priority Zone rooftop garden (Durban, KwaZulu-Natal)	(Priority Zone Durban, 2013; Pillay, 2017)
	Community garden	Shared public or private land used for the cultivation of agricultural goods by a group, mainly for their own consumption	Siyakhana Food Garden project (Johannesburg, Gauteng)	(Bauta et al., 2011; Nicolle, 2011; Nino et al., 2020)
	Horticulture	Public land used for agricultural purposes to grow products on a large scale product (fruits, vegetables, and other plants) used or sold to the public for medicinal purposes, food and aesthetic gratification	Philippi Horticultural Area (Cape Town, Western Cape)	(Battersby-Lennard and Haysom, 2012; Dewar et al., 2013; Donn-Arnold, 2019)
	Rooftop farming	Comparable to a green roof but refers to the agricultural practice of cultivation of fruit and vegetables on a roof surface	The Priority Zone rooftop garden (Durban, Kwazulu-Natal)	(eThekwini Municipality., 2011, p. 11; Priority Zone Durban, 2013; Pillay, 2017)
Urban natural remnants	Urban forest	An area of natural or planted trees in and around urban areas (urban woodlands, natural forests; plantations; individual trees along right of-way spaces, including streets, or verges, or pathways)	Johannesburg urban forest (Johannesburg, Gauteng)	(Schäffler and Swilling, 2013)
	Existing natural remnant areas	Existing natural remnants like natural and restored native ecosystems and other natural fragments of naturally occurring or rehabilitated indigenous vegetation cover of local biomes that could be included in urban nature reserves	Rondebosch Common Urban Nature reserve (Cape Town, Western Cape)	(Dyssell, 1993; The City of Cape Town, 2010)
	Urban natural wetland and ponds	Waterbodies formed by means of sediment deposits on river banks with either permanently or periodically water and a variety of characteristic flora and fauna. Wetlands are found in and around cities and suburbs and are often placed under nature reserves for protection	Khayelitsha wetland (Khayelitsha, Cape Town, Western Cape)	(The City of Cape Town, 2016; African Centre for a Green Economy, 2017; Mathenjwa, 2017)
	Urban river or stream	Linear running water resources flowing in urban areas with artificial or natural banks characterized by vegetation and other sediments	Liesbeek urban river (Cape Town, Western Cape)	(Bhikha, 2013; Brill et al., 2017; Fisher-Jeffes et al., 2017; Muntjewerff et al., 2019; Kotzé, 2020)

(Continued)

TABLE 1 | Continued

		GI element	Case-study	Sources
Public green space	Urban park and child-friendly space	Typically a publically accessed green space that includes features of vegetation (e.g., trees, lawns, and flowerbeds) and water features, walking paths, play areas, range of activities, seating, picnic tables, and restrooms	Green point urban park (Cape Town, Western Cape)	(The City of Cape Town, 2016; Landman, 2019)
	Botanical garden	Institutions holding public space for the conservation of diverse biodiversity for research, education, display (ornamental) and recreational activities.	Kirstenbosch Botanical Garden (Cape Town, Western Cape)	(Willis and Morkel, 2008; Titus and Spencer, 2015)
	Green sport facilities	Cultivated and fertilized grass turf suited for sport activities (e.g., golf courses, football fields, hockey fields etc.).	Grimbeek Park Golf course and Heilige Akker sport grounds (Potchefstroom, North-West)	(Cilliers and Cilliers, 2015 and personal observations)
	Health clinic garden	Gardens cultivated around health facilities, providing a green space to produce fruit, vegetables and medicinal plants for patients of the health facility and surrounding community.	The Jan Kempdorp community health center garden (Jan Kempdorp, Northern Cape)	(Muller, 2019)
Private	Private home gardens	Privately owned space adjacent to domestic dwellings that may accommodate a variety of flora species for ornamental, food, medicinal, and construction material uses	Private home gardens in Cosmo city (Johannesburg, Gauteng)	(Adegun, 2018)
Informal green spaces	Riverbank greenery	Vegetated publically accessed spaces along, streams, and canals	Oewersig riverbank green space (Potchefstroom, North-West)	(Cilliers and Cilliers, 2015 and personal observations)
	Roadside or railway verged greenery	Intersections or strips of land bordering roads and railway embankments that could be a few centimeters to a few meters in size consisting of vegetation, habitats, forest, or gardens	Roadside greenery on Brakfontein road (Pretoria, Gauteng)	Personal observations

principle, referring to the capacity of a space to provide multiple ES within the same space in the landscape.

A total of 71% of respondents selected the "Multifunctionality as urban land use concept" definition, confirming findings in the literature (Rodenburg and Nijkamp, 2004, p. 274); 19% selected the "Multifunctionality as a GI planning principle" definition; and 10% selected the definition for "Multifunctionality in an urban landscape" (Van Zyl et al., in press). The majority (71%) of respondents reported considering GI at some point in previous projects. A lack of implementation strategies (25%) and knowledge (17%) on more ecologically minded approaches were cited to explain a lack of more significant and consistent integration of these approaches (Van Zyl et al., in press). As substantiated by these findings, the relationship between GI and multifunctionality to generate multiple ES is not yet widely recognized in South African planning.

In recognition of the literature reviewed, findings by Van Zyl et al. (in press) and the recommendation by Du Toit et al. (2018, p. 258) for local and context-based assessment of GI and the call of Hansen et al. (2017, p. 34) for the establishment of multifunctionality inventories to assist decision-makers, the following section turns to South Africa as research focus to (1) investigate the ES generated by selected South African GI elements (based on **Table 1**); and (2) determine the multifunctionality of these GI elements as a framework to guide urban planners to promote multifunctionality through GI in planning. The methodology followed is detailed below.

METHODOLOGY

A qualitative research approach was employed using case studies to explore South African green infrastructure typologies and their multifunctionality. Case studies were identified based on criterion sampling and purposeful sampling. Criterion sampling involves selecting a case that meets a predetermined set of criteria (Omona, 2013, p. 180), informed for this research by the inventory of GI elements generated in the literature investigation (sections Ecosystem Services Delivered By Green Infrastructure, Green Space Typologies as Green Infrastructure Elements, and Multifunctionality as a Multifaceted Concept) (**Table 1**, first three columns). The GI elements identified in case studies were classified under six main GI element groups, namely (1) gray-green designed elements; (2) urban agriculture; (3) urban natural remnants; (4) public green space; (5) private green space; and (6) informal green space with 19 GI element examples (see **Table 1**). Following broad criterion sampling, potential case studies were further refined by means of purposeful sampling. Specific cases were selected that provided examples of GI elements from the local context that delivered "information-rich" evidence on the potential generation of ES in these categories. Determinations were made by consulting academic publications and gray literature as sources of textual data (documents) to inform the selection of cases (Bowen, 2009, p. 29). **Table 1** (columns 4 and 5) illustrates the purposefully selected examples of South African GI elements included following the sampling procedure.

TABLE 2 | Summary of the benefits of multifunctionality in relation to the aspects of sustainability.

Aspects of sustainability	Benefits of multifunctionality
Environmental aspects	• Bio-physical characteristics provide amplified ecological functions (e.g., protecting ecosystems, representing natural habitats and life support systems for humans) which are perceived as ES with social and economic values • Promotes the appreciation and protection of natural remnants in urban areas
Social aspects	• Diversification of combined activities that attract people to the space • Increasing number of possible activities to enhance positive usage of a space by diverse user groups • Benefiting social cohesion via different levels of social interaction • Establishing more lively, attractive, and safe spaces • Enriching identity and sense of place • Contributing to human health and well-being
Economic aspects	• Encouraging local economic activity and growth • Enhancing attractiveness to attract tourists and new residents • Increasing local land and property values • Positive impact on the workforce, with augmented productivity • Delivering multiple municipal services (e.g., combined water, waste, and storm water management)

Sources: *Douglas and Ravetz (2011, p. 252); Konijnendijk et al. (2013); Schäffler et al. (2013, p. 12); Mejía et al. (2015, p. 530); Molla (2015, p. 93); Hansen et al. (2019, p. 13); Živković et al. (2019).*

For the assessment of the ES generated by the selected examples of South African GI elements a "self-assessment" approach was followed. The self-assessment of qualitative data were based on two main aspects: (1) the identification of criteria for the assessment, and (2) determination of the extent to which criteria were met (Falchikov and Boud, 1989, p. 529). Based on the first aspect of the self-assessment approach, each selected case study was scrutinized and evaluated using a matrix of criteria to identify the potential ES provided (see **Supplementary Table 1** as an example of the assessment of the ES generated by the University of Pretoria rain garden), again based on a review of available literature on the selected examples. The documents exploited were selected as they provided detailed descriptions or discussions of one of the selected GI element examples (e.g., Muller, 2019, on the Health Clinic gardens). Direct observations by the researchers, as a recognized data gathering instrument in qualitative research (Farthing, 2016, p. 133), were also employed where no discussions of case studies were represented in the literature, for example for the golf course, other sports facilities and some of the informal green spaces included. A summary of the "provision capacity" or the total ES generated by each case study in terms of GI elements is given in **Supplementary Table 2**.

For the second aspect of the "self-assessment" method—"determination of the extent to which criteria were met," a matrix was used to determine the "level" of the four ES categories recognized within each GI element example by means of the ranking criteria captured in **Table 3** using the summary in **Supplementary Table 2** with the assessment results also in **Table 3**. Following the ranking procedure, a verdict on the level of multifunctionality presented was provided based on the matrix (**Table 3**).

RESULTS AND DISCUSSION

A comprehensive discussion of the results for each GI element and case study following the aforementioned analyses will not be provided. Instead, this section provides a broad overview of results, firstly presenting the ES identified in each case study (**Supplementary Table 2**), followed by findings on the multifunctionality of each GI element (**Table 3**). A framework of GI typologies and the ES provided by each GI element using case studies is created accordingly to inform planning decision making (**Supplementary Table 2** and **Table 3**). Additional discussions follow based on the results illustrated.

The results captured in **Supplementary Table 2** and **Table 3** demonstrate that most GI elements generated several ES simultaneously and can thus be regarded as multi-functional. Two groups of GI elements specifically presented higher levels of multifunctionality, namely gray-green designed elements and urban natural remnants. On the whole, the majority of elements delivered medium (rooftop farming, the urban park, and child-friendly space, botanical garden, and riverbank greenery) and high (urban wetland and private home gardens) multifunctionality scores. Certain informal green spaces (except riverbank greenery), were, however, classified as "mono-functional". Summing the scores (ranking scales) of the different GI elements (**Table 3**) providing specific ES out of a possible score of 60 provide an indication of the general prominence of the different ES categories identified. All examples generated regulating ES (total scale score of 54), especially local climate regulation and air purification, as well as cultural ES (total scale score of 53), mostly by hosting recreational activities or contributing to aesthetic value. The majority of GI elements also generated habitat and supporting ES in support of other ES (total scale score of 50). Provisioning ES were identified the least (total scale score of 29)—potentially indicating a more specialized category and the need to include extremely specific GI elements when these ES are required, for example urban agricultural uses or gardens. Several studies from the Global South suggest that these areas and the various ES they provide need to be specifically and pro-actively included in urban planning and management (Shackleton, 2021; Steenkamp et al., 2021), as they are generally not recognized as "official land use(s) in many city plans" in the Global South (Pauleit et al., 2021). Private gardens proved to be highly multi-functional. Lower income areas in SA are often endowed with less private and public green spaces than middle- and higher income areas and the equitable provision of urban GI, including planning for larger residential plots requires special consideration (McConnachie and Shackleton, 2010; Venter et al., 2020, Shackleton, 2021).

TABLE 3 | Self-assessment criteria and results of the different GI elements in the case studies.

Assessment criteria

1) The ranking scale for assessing the level of ES recognized within the four ES categories: / **2) The rankings scale allocated for the multifunctionality of each GI element:**

RANKING	THE LEVEL OF ES RECOGNIZED WITHIN THE FOUR CATEGORIES (Provisioning, regulating, cultural, and habitat and supporting services)	NUMBER OF ES CATEGORIES RECOGNIZED	ASSESSMENT OF THE MULTIFUNCTIONALITY LEVEL
0	No ES recognized within a category	*One* category	Mono-functional
1	One of the ES recognized within a category—*Weak*	*Two* categories with a ranking of 3	Low level multifunctionality
2	Two of ES recognized within a category—*Medium*	*Three* categories with a ranking of 3	Medium level multifunctionality
3	Three or more of the ES recognized within a category—*Strong*	*All* (*four*) categories with a ranking of 3	High level multifunctionality

Assessment results

GI elements	Provisioning	Regulating	Cultural	Habitat and supporting	Multifunctionality level
Gray-green designed elements					
Green roof	2	3	3	3	Medium
Green wall	0	2	3	3	Low
Sustainable urban drainage systems (constructed wetland)	1	3	3	3	Medium
Sustainable urban drainage systems (rain garden)	1	3	3	3	Medium
Urban agriculture					
Community garden	2	2	3	3	Low
Rooftop farming	2	3	3	3	Medium
Horticulture	2	3	3	2	Low
Urban natural remnants					
Urban forest	2	3	3	3	Medium
Existing natural remnant areas	0	3	3	3	Medium
Urban wetland	3	3	3	3	High
Urban river or stream	1	3	3	3	Medium
Public green space					
Urban park and child-friendly space	1	3	3	3	Medium
Botanical garden	2	3	3	3	Medium
Green sport facilities	1	3	3	0	Low
Health clinic garden	3	2	3	3	Medium
Private green spaces					
Private home gardens	3	3	3	3	High
Informal green spaces					
Cemeteries or burial grounds	0	2	1	0	Mono-functional
Riverbank greenery	3	3	3	3	High
Roadside or railway verged greenery	0	1	1	3	Mono-functional
Vacant land	0	3	0	0	Mono-functional
Total scores	**29**	**54**	**53**	**50**	

Findings indicate that whilst some individual values presented by certain GI elements may be small, ultimate value is found in the potential to provide multiple ES. For example, wetlands deliver substantial value by contributing to all ES categories, as validated by Bolund and Hunhammar (1999), De Groot et al. (2002), Gómez-Baggethun and Barton (2013), and Pfab et al. (2017, p. 10). Specific mention should also be made of the contributions delivered by natural remnants that have been discounted in the past (Muller et al., 2010, p. 3; Planchuelo et al., 2020, p. 1). The Global South is characterized by a much higher native biodiversity than the Global North and therefore urban planning in the Gobal South needs to be more vigilant to protect sensitive ecosystems and populations of species (Shackleton et al., 2021, p. 15). Many South African municipalities fail to plan for fragmented natural areas, but others have included these spaces given their location in biodiversity hot spots (Durban) (Boon et al., 2016; McLean et al., 2016) or as part of systematic conservation plans (Johannesburg and Pretoria) (Pfab et al., 2017).

Gray-green designed elements exhibited medium to high levels of multifunctionality and present great potential. South Africa has only recently started to engage with elements such as sustainable urban drainage systems (SUDS) through water sensitive urban planning and design (WSUD) solutions that incorporate constructed wetlands, rain gardens and bioswales (Fisher-Jeffes et al., 2017). Although WSUD has not yet been acknowledged in spatial planning in South Africa on a large scale, certain examples of implementation from Cape Town and Johannesburg have emerged (Carden et al., 2016, 2018, Mguni et al., 2016; Madonsela et al., 2019). Several barriers and limitations to the implementation of SUDS in cities in sub-Saharan Africa have been acknowledged (e.g., Mguni et al., 2016), especially the need for "social acceptance and capacity building" amongst planners (Cilliers et al., 2021) to address inequality and build a "community of practice" to implement WSUD (Carden et al., 2016).

CONCLUSIONS AND RECOMMENDATIONS

In drawing conclusions and arriving at recommendations, it is pertinent to acknowledge certain limitations of this research. The research was exploratory in nature, presenting a preliminary investigation of the potential links between multifunctionality and GI as a principle for consideration in urban planning practice. The focus on the South African context further limited the scope of the paper and in some cases there is a general lack of literature and existing empirical evidence pertaining to case studies of GI elements and ES in South Africa.

Nevertheless, the literature and case study results provided sufficient evidence of the potential in the application of various GI elements to provide multiple ES. These varied contributions may manifest as a result of the multi-functional nature of many GI elements as spaces that fulfill multiple roles to the benefit of more sustainable development outcomes. These benefits can be reconciled with multiple aspects of SDG 11 and its targets such as reducing the environmental impacts of cities by focusing on air quality and waste management (enhanced regulating ES) and by providing safe, inclusive and accessible green and public spaces (enhanced cultural ES) to name a few, but also with other SDGs and their targets (Maes et al., 2019). Whereas approaches to achieve multifunctionality through GI planning have been recognized, both the international literature and empirical evidence from South Africa (based on the explorative research captured in this paper) suggest that the approach is not widely embedded in urban planning practice. This is supported by findings presented by Van Zyl et al. (in press) on the vast majority of South African respondents not relating multifunctionality to GI planning and the lack of implementation strategies and knowledge on more ecologically minded approaches in explanation of a lack of more significant and consistent integration of GI in past projects in South Africa (Lategan and Cilliers, 2014; Cilliers and Cilliers, 2016, p. 11; Pasquini and Enqvist, 2019, p. 9) but also in the Global South (Cilliers et al., 2021, Pauleit et al., 2021).

This research addressed this knowledge and application gap by further investigating the ES (**Table 3** and **Supplementary Table 2**) generated in case studies of specific South African GI elements (**Table 1**) and determining the multifunctionality of these elements as a guide (preliminary framework) (**Table 3**) for the broader application of multifunctionality through GI by South African planners. The investigation delivered novel contributions by presenting a comprehensive list of GI elements (**Table 1**), including previously neglected elements like private home gardens (Cilliers et al., 2018; Lindley et al., 2018; Shackleton et al., 2018), botanical gardens (Ward et al., 2010), green spaces used for urban agriculture (Lin et al., 2017, p. 115; Lindley et al., 2018, p. 337) and fragmented natural areas (remnants) (McLean et al., 2016) and ranking their multifunctionality.

Hölting et al. (2019) stress that optimal multifunctionality is not simply achieved by following a "the more ES the better" approach, but on the balance of numerous ES categories (provisional, cultural, regulating, and supporting services) according to context to transform existing mono-functional spaces and develop multi-functional uses. In addition, a networked approach to the achievement of multifunctionality may be sought in which multiple spaces fulfill different roles and provide different combinations of ES to address potential conflicts and synergies to the benefit of the broader urban environment. This is supported by the view of GI as an interconnected network referenced in the definition synthesized for this paper and the literature reviewed (e.g., Burton and Rogerson, 2017), inter alia by providing sufficient and equitable distribution of urban GI, especially needed in Global South cities (Shackleton, 2021, p. 217-219). For multifunctionality to be realized in the long-run, local data needs to be gathered that will convince decision-makers by presenting results of ES that contribute to quality green space, quality of life and quality urban environments (Mell, 2010, p. 58). Andersson et al. (2021) stressed the importance of local context in terms of the provision and flow of ES in cities as social-ecological-technical systems (SETS) with the aid of six case studies from the Global North. Careful

TABLE 4 | Checklist to evaluate GI elements.

Checklist item	Yes	No
Is there a synergy between multiple ecological, social, and economic functions of the green space to augment the ecological, social, and economic benefits of the green space?		
Are green resources combined with other types of urban (gray) infrastructure (e.g., GI elements like green roofs and walls, or sustainable drainage systems)?		
Does the green space deliver within multiple ES categories?		
Did the planning process for the green space establish common ground for multiple disciplines and other departments (e.g., current local governance authorities and planning structures) in collaboration with non-governmental stakeholders (to share input)?		

consideration of the local context is also regarded as an important emerging issue in advancing the discipline of urban ecology and its implementation in terms of planning, management and design in the Global South, not only in terms of environmental aspects but also the divergent economic, cultural, social, and political realities facing the Global North and South (Cilliers et al., 2021, Du Toit et al., 2021).

Context-based municipal GI "registers" following the suggested preliminary framework, that capture locally implemented GI elements to identify a settlement's existing use of GI typologies, to maintain existing GI elements and recognize potential opportunities or gaps for the development of new GI elements, all in terms of the provision and flow of ES, could guide planning toward increased multifunctionality. Whilst the current study found urban wetlands and private home gardens to present the highest levels of multifunctionality, other contexts may deliver contrasting, unique results and implementation possibilities highlighted by the completion of "registers" and the execution of multifunctionality assessments. Such endeavors must be informed by stakeholder engagement processes in recognition of multifunctionality as a concept intrinsically linked to the fulfillment of multiple needs. Thus, incorporating "need-assessments" that consider how existing green spaces meet stakeholder needs and how these spaces could be improved or new spaces developed to contribute to a more sustainable environment (Boulton et al., 2018, p. 97).

Depending on the results of such processes, three management strategies for the implementation of multifunctionality through GI planning can be made (Ahern, 2007). Firstly, an offensive or opportunistic strategy relating to planning for new multi-functional green spaces through for e.g., (1) combining functions for simultaneous integration for instance developing sport fields as recreational uses that also provide regulating ES such as storm water retention or adding edible plant species to roadside verges, child-friendly spaces or green walls increasing provision ES which are especially important for the Global South (Shackleton, 2021, p. 217-219), (2) by stacking multiple functions vertically to capitalize on potential synergies through multi-layered arrangements, for example infiltration systems under buildings or parking areas and green roofs on buildings, not only increasing regulating ES but also provisioning and supporting ES, (3) differentiating and coordinating ES and functions in the same space, but shifting roles at different time intervals, for example restricting the use of hydrological systems in terms of the cultural ES they provide during high flow periods protecting their regulating and supporting ES (Rodenburg and Nijkamp, 2004, p. 274; Selman, 2009, p. 47; Ahern, 2010, p. 147). These approaches are also reconcilable with the four dimensions of multifunctionality in urban planning mentioned in section Multifunctionality as a Multifaceted Concept. Secondly, a protective strategy that employs preventative actions to pro-actively preserve and maintain existing multi-functional GI elements, for example natural remnant areas, to avoid disturbances. Lastly, a defensive strategy that employs measures to "defend" existing multifunctional GI elements (e.g., existing natural remnants or parks) that are threatened by development pressure and constraints (Hansen et al., 2016, p. 54). The importance of protecting urban GI with high native biodiversity in Global South cities has also been emphasized, as mentioned previously (Shackleton et al., 2021, p. 15).

Finally, to achieve multifunctionality through GI planning a "checklist" (**Table 4**) informed by the literature reviewed and empirical results delivered, is provided. The checklist could aid urban planners within their specific environmental, economic, cultural, social and political contexts to identify existing multi-functional spaces (for the employment of the protective and defensive strategy) or to guide them toward the implementation of new multi-functional spaces (for the employment of offensive or opportunistic strategies) as part of standard planning procedure. Relating to the last checklist item on different disciplines and stakeholders, Huston's (2018) findings on a lack of GI education and limited interpretations of multifunctionality (Van Zyl et al., in press), both qualified and trainee urban planners should be educated on the nexus between multifunctionality and ES and the implementation possibilities related to various GI elements/inventories. This education should become part of planning curricula in higher education and courses for continuous professional development to empower urban planners to function with authority as part of transdisciplinary teams (Cilliers et al., 2014) and overcome disciplinary "silos" to re-scope the outlook of urban planning practice (Tan, 2017, p. 18) toward a more ecological point of departure (Ahern et al., 2014, p. 255; Tan, 2017, p. 18). This may require cross-sectoral and cross-departmental cooperation to integrate knowledge and expertise from different fields (Hansen et al., 2017, p. 66). These fields include professionals such as urban planners, engineers, landscape architects/designers and ecologists and other departments, for example local governance authorities and planning structures in collaboration with non-governmental stakeholders like public and private landowners, voluntary organizations, as well as individuals and communities toward integrated strategic GI plans that espouse multifunctionality (Selman, 2009, p. 50; Mell, 2010, p. 39; Pauleit et al., 2011, p. 257; Ahern et al., 2014; Lennon et al., 2016, p. 850; Wei, 2017, p. 19; Cilliers et al., 2021, p. 390). Cooperation may be challenging as Childers et al. (2015, p. 3781) argue that the only way in which a transformative integration between urban ecology and planning and design can be realized is if we can successfully train and educate a "cadre of ecologically literate urban designers and engineers; design-literate, engineering-conscious ecologists; broad-thinking and holistically inclined planners, and place-aware and activist city residents."

The GI typologies and their ES provided as the outcome of this research presents a preliminary framework from which to approach all above recommendations to mainstream multifunctionality through GI in planning. The approach holds potential to advance the sustainable development agenda, aligned to SDG 11 and others, for SA and the rest of the Global South where "weak or constrained planning and implementation of policies, plans and regulations" are regarded as major impediments (Du Toit et al., 2021), but also to address possible disparities between the Global South and Global North in GI provision (Cilliers et al., 2021; Du Toit et al., 2021; Pauleit et al., 2021). Such a framework would align to a systems perspective to urban governance, and potentially support the better management of the complex cause and effect relationships between social and ecological phenomena (Orr, 2014). Acknowledging that cities are complex social-ecological-technical systems (SETS) could support Planners and Authorities to better understand multifunctionality in urban green infrastructure planning and embed it in broader spatial planning approaches.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

BV is the lead author, with components of this paper based on research for her Masters in Urban and Regional Planning. LL, EC, and SC were research supervisors of this research project. All authors contributed equally to the generation of the concept, writing, and revision of text for this paper and have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

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