Urban Ecosystems (2024) 27:895–907
https://doi.org/10.1007/s11252-023-01477-y

A transdisciplinary multiscaled approach to engage with green infrastructure planning, restoration and use in sub-Saharan Africa

Christina A. Breed[1] · **Kristine Engemann**[2,3] · **Maya Pasgaard**[2,3]

Accepted: 17 November 2023 / Published online: 28 December 2023

Abstract
The systematic integration of green infrastructure (GI) concepts in urban planning shows promise to reduce environmental hazards; while creating sociocultural benefits. However, cities in sub-Saharan Africa face rapid urbanisation and are challenged by the degradation of existing GI, increasing their vulnerability to climatic risks. This paper presents the findings of a transdisciplinary research project that investigated GI planning in the City of Tshwane, South Africa, over two years. The researchers conducted a community survey, an on-the-ground rapid assessment of multifunctional benefit provisions, first-hand observations of local stormwater systems, reviewed policy documents and conducted semi-structured interviews with metro officials. To integrate the above findings, four design studios and eight co-creation workshops were held that explored GI spatial planning in the city. The researchers examined the uptake of GI planning principles, and the challenges, opportunities and local proposals for GI applications, and here synthesised some main conclusions. Despite many well-known challenges, GI opportunities include creating socioeconomic incentives for stronger human-nature relations, providing for multifunctional benefits and anchoring GI in local communities. Interactive research can facilitate increased local awareness and engagement, but access to GI benefits is physically constrained and socially determined by knowledge, networks and safety factors. Based on the above findings, the researchers propose locally adapted planning strategies to enhance GI: creating opportunities for GI access and co-ownership, encouraging multifunctional, safe and flexible GI, supporting multiscale GI integration, and strengthening collaborative governance. A joint GI vision can reinforce city ownership along with flexible and creative design alternatives that are rooted in local communities.

Keywords Design · Global south · Green space · Planning principles · South Africa · Urban

Introduction

Due to challenged and underfunded governance regimes and planning systems, cities in sub-Saharan Africa (SSA) suffer the loss and depletion of natural resources, which have negative consequences for the environment and green infrastructure (GI). With only a few exceptions, SSA countries show a weak research interest in GI (Titz and Chiotha 2019), while researchers report a lack of appreciation of its value and low awareness of its full benefits (Breed et al. 2023; Du Toit et al. 2018; Takyi et al. 2022). As a consequence, implementation policies and strategies for GI concentrate primarily on green growth, integrated energy and climate adaptation plans, while ecological network integration and the socioeconomic and health benefits of GI are neglected in the sub-continent (Pauleit et al. 2021). Green infrastructure planning research in SSA suggests that current planning practices are problematic in several countries (Titz and Chiotha 2019; Guenat et al. 2020). Studies report challenges from a management perspective (Cobbinah and Nyame 2021), which includes the lack of enforcement of conventional GI policies and plans (Takyi et al. 2022), and obstacles in strategically adopting and integrating different GI typologies into planning practices and policy (Girma et al.

✉ Christina A. Breed
ida.breed@up.ac.za

[1] Department of Architecture, University of Pretoria, Bag X 20 Hatfield, Pretoria 0028, South Africa

[2] Section for Ecoinformatics and Biodiversity, Department of Biology, Aarhus University, Ny Munkegade 114, 8000 Aarhus C, Denmark

[3] Center for Biodiversity Dynamics in a Changing World (BIOCHANGE), Department of Biology, Aarhus University, Ny Munkegade 114, 8000 Aarhus C, Denmark

2019). Barraclough et al. (2022) illustrate the disconnect between GI stakeholders and government networks, which results in a lack of cultural services, such as outdoor recreation, in management agendas. In line with this, SSA studies recommend governance structures that support the collaboration, coordination and co-development of GI (Guenat et al. 2020), with co-ownership and participatory stakeholder partnerships (Ogu 2000). Such co-development strategies seek to enlist the entire urban community's financial and material resources, and expertise towards improved GI. Co-creation strategies in the field of GI also contribute to enhancing the awareness and knowledge of society and stakeholders regarding GI, balancing interests, benefits and responsibilities between the relevant stakeholders, and making the whole process transparent and inclusive towards effective shared governance.

Building on the above GI literature from SSA, this study on Integrative Green Infrastructure Planning (GRIP) focused on knowledge exchange and capacity building to improve the coordination, planning and maintenance of green and open spaces in the City of Tshwane, South Africa. In addition, the research aimed to co-develop context-specific proposals and actionable strategies towards realising the multifunctional benefits of GI in Tshwane.

In the SSA context GI has been defined as "strategically planned or unplanned, public or private, managed or unmanaged natural or semi-natural vegetation that delivers varied ecosystem services", (Takyi et al. 2022). Our study conforms to this definition as it bridges consideration for both managed and unmanaged urban GI. Whereas formally managed GI is often designed and programmed to provide a single or few specific benefits such as sports facilities, synergies linking biodiversity conservation, human health and socioeconomic benefits are often overlooked (Breed et al. 2015) or unattained due to colonial legacies or apartheid planning, which include barriers such as access restrictions (Landman 2019; Baruah et al. 2021). Informal unmanaged GI is without formal recognition or management (Rupprecht & Byrne 2014; Lurdes et al. 2021). For the same reasons, some communities only have access to unmanaged green spaces (Lurdes et al. 2021; Takyi et al. 2022) and these areas hold the potential to deliver a spectrum of GI-related nature-based benefits, including biodiversity, climate adaptation and a variety of sociocultural uses (Cocks et al. 2016; Du Toit et al. 2018). However, to overcome the above challenges faced by GI, and move within reach of the potential benefits, a sound but local vision and definition for GI *planning* is required, to emphasize the importance of "design and management of an integrated network" that can enable the delivery of "a wide range of ecosystem services" (European Commission 2013).

Materials and methods

Study area

Like many SSA cities, the City of Tshwane Metropolitan Municipality (Tshwane) is characterized by biotic and cultural diversity and steep socioeconomic gradients (Cilliers et al. 2014). The administrative capital of South Africa is situated in the most densely populated province of Gauteng, the economic hub of South Africa (see Fig. 1), with rich biodiversity pressured by development and rapid urbanisation (Pfab et al. 2017). Tshwane is the largest local metropolitan city by area, covering 6345 km2 with a population of 3,31 million people (City of Tshwane 2020). Due to geographic and political-historic reasons, Tshwane has considerable local population density variations. Tshwane is relevant for upscaling lessons as it demonstrates many challenges experienced in other SSA cities. Current challenges include urban sprawl, growing informal settlements, deteriorating infrastructure, rising poverty levels, inequality (Landman 2019) and a lack of access to GI and its services (Du Toit et al. 2018). Therefore, the findings of this study have relevance for SSA and beyond.

This study is a comprehensive transdisciplinary study on urban GI in Tshwane, considering both managed and unmanaged GI. Although no map exists that distinguishes managed and unmanaged GI in Tshwane, Brom et al. (2023) have illustrated the spread of publicly accessible GI distribution in Tshwane and discussed their level of multifunctionality. To take cognisance of the full spectrum of existing potentials and challenges of GI in the city, two municipal-owned

Fig. 1 The geographic position of the City of Tshwane in South Africa and the two study sites at 1) Mabopane and 2) Atteridgeville

100-hectare study sites were co-selected with municipal stakeholders to consider informal and unmanaged blue-green spaces with social and ecological potential on a river system (see Fig. 1).

Data collection and analyses

The project extended over two years, with most of the fieldwork conducted between May 2021 and October 2022. Table 1 summarises the eight different methodological approaches that were followed for data capturing and analyses—the focus, sampling and time frames allowed for consideration of multiple perspectives. These approaches engaged with GI in three spheres (see Fig. 2): GI on the ground, GI process and planning, and co-developing GI proposals, with methods to collect data on both managed and unmanaged GI from different sources and other methods to integrate stakeholder perspectives towards GI proposals.

GI on the ground comprised a 1) community survey that was conducted to understand how people use green space, the benefits and risks they see, their involvement in decisions and activities, and their hopes and ideas for change; The researchers rapidly assessed 2) multifunctional benefit provisions such as physical access, attractiveness, biodiversity, health and climate benefits; First-hand observations of 3) local stormwater systems' locations and conditions of outlets were made; 4) A vegetation survey recorded plant species and soil samples to assess the ecological integrity at each site.

At a *GI process and planning* level, the study reviewed 5) policy documents, and conducted 6) semi-structured interviews with metro officials to consider the uptake of GI planning principles, and the challenges, opportunities and local proposals for GI applications (also see Breed et al. 2023).

To *co-develop local GI proposals,* that integrate the findings from the above methods, the researchers held 7) design studios with postgraduate students in landscape architecture, that integrated input from across sectors with geospatial and physical site assessments; while 8) Co-development workshops opened up avenues and brainstormed GI spatial planning and design applications with public sector officials and private sector consultants working with GI in Tshwane.

Findings

Green infrastructure planning challenges in Tshwane of managed and unmanaged green spaces include the scarcity of resources, low valuation of GI, competing interests, conflicting policies, lack of enforcement and political will, poor collaboration and a need for technical knowledge and skills (Breed et al. 2023). Metro officials expressed their frustrations in interviews, such as: "*Environmental compliance in the city is very low, internally and externally…*"; "*It's as if the environment doesn't matter*"; "*Management and maintenance of facilities is a problem as the budget is very, very limited.*"

On-the-ground challenges include unclear and contested ownership, current informal and illegal uses that infringe on vulnerable ecologies, insufficient maintenance, invasive plants, safety risks, gender inequalities, soil erosion, sewer leaks and dumping that could decrease ecological integrity and increase risks of flooding due to blocked inlets (see Fig. 3) (Engemann et al. in review; Pasgaard et al. 2023). As expressed in an interview by a metro official: "*Wetlands, unfortunately, are the dumping site for disposing of building rubble everywhere.*"

There is a general lack of protection and management targeting biodiversity conservation and restoration in unmanaged green spaces. The lowest vegetation sensitivity was recorded in the areas most influenced by humans, and in the marshy areas around the rivers – with few plant species, heavy pollution and infestation by invasive species (Engemann et al. in review). The most sensitive vegetation communities were in the dry, terrestrial areas due to the many native plant species (Engemann et al. in review). The protection of high-value terrestrial areas is lacking, and the current conservation and management of river systems are insufficient. These findings point to a general conflict between human presence and biodiversity (see Fig. 4). This is summarized by this quote from a metro official: *"What's the point of biodiversity if no[one has] access?"* or this developer stating*: "Because if it is not going to be used, it is not going to be maintained, it makes everything else irrelevant."*

The researchers further found that most residents who visit unmanaged spaces for prolonged periods used the spaces for active (sports, playing, relaxing, socialising) or passive (relaxation, meditation, spiritual use) leisure. A few people used the areas for economic (collecting plants and/or business, trading) or spiritual purposes (Engemann et al. in review). These results show both the existing benefit provision and the untapped potential of unmanaged spaces. The researchers accentuate that people's access to GI benefits is both physically constrained and socially determined by knowledge, networks and safety factors (Pasgaard et al. 2023). This is understood by a developer that stated: "*Because if people don't feel safe, it [green space] doesn't get used",* or a metro official that acknowledged that:"*The community needs to take ownership and they need to be informed and they need to be educated about these things."*

While more than eight out of ten respondents expressed a willingness to participate in community-driven activities (e.g. facility maintenance, community patrols, gardening or youth education), many felt held back by time and resource constraints, concerns for their safety, and lack of organisation and opportunities for involvement (Engemann et al. in

Table 1 Integration of transdisciplinary research methods in a collaborative multiscaled GI approach

	Methodological Approach	Method and instrument(s)	Sampling period(s)	Sample population and/or size	Data capturing and analyses	Focus and Integration
GI on the ground	**1. Community survey**	Surveys were conducted in person by local enumerators around the study sites with closed-ended, open-ended and multiple-choice questions Questions were structured around Environmental Justice dimensions of distribution, procedure, and recognition	October 2021 and March 2022	Purposeful sampling that seeks representation in gender, age, and geographical spread in the study area 200 residents living near (100 at each) study site. Sampling points (busy street corners) were spread evenly across 5 zones in each site	Data capturing through Epicollect and analysis through MS Excel During the analyses, descriptive statistics of socioeconomic indicators were calculated for all respondents and aggregated by each study site. Then, circle plotting in R was used to elucidate patterns of use, access, activities, and perceived benefits and barriers from the study sites	Unmanaged GI **Resident use**, activities barriers and benefits related to their urban green spaces Findings integrated with spatial access and infrastructure conditions analysis (in 2 and 3) to understand local social contextual realities
	2. GI multifunctionality rapid assessment	Transect walks on sites with Likert scale questionnaire covering categories of physical access, attractiveness, biodiversity, human health and climate benefit Each transect was evaluated based on 43 questions, concluding with a general site evaluation based on 48 questions	October 4–15, 2021	Transects were plotted to run perpendicular to the surrounding street and were spaced out at ~ 200 m intervals for each ~ ¨100 ha site. This resulted in 10–15 transect walks for each site	Benefit index values were calculated for each benefit category across all individual transects and jointly for each study site. The index values were calculated by recording all questions from the transect and site surveys to numeric values between 0–1 and calculating the mean across all questions falling within a category	Unmanaged GI Multifunctional benefit provision **for residents** Findings integrated with community survey (in 1 e.g. nature perceptions) and design proposals (in 7 e.g. biodiversity protection and restoration)

Table 1 (continued)

	Methodological Approach	Method and instrument(s)	Sampling period(s)	Sample population and/or size	Data capturing and analyses	Focus and Integration
	3. Stormwater systems observations	Site visits and observations are needed to explore the systems for stormwater management in the study areas and identify existing conditions or practices with risks of flooding and potential for local safety, health, or ecosystems	March 2022	One visit at each site surveying the type, dimension, condition, and management of all stormwater outlets along the edges of each site using Epicollect Informal conversations with local residents to understand local social conditions	GIS analyses of the flow paths and sub-catchments based on a digital elevation model (DEM) from NASA (https://www.earthdata.nasa.gov/) and the surveyed stormwater outlets to identify areas prone to flooding Analyses using Scientific and grey literature, incl. reports from SA authorities, to understand local challenges and propose solutions for stormwater management	Unmanaged GI Determine stormwater management status and needs to propose initiatives to **mitigate local impacts** through adaptation measures Integrative part of multifunctionality assessment (in 2) and critical knowledge for addressing flooding caused by climate change in design proposals (in 7)
	4. Vegetation survey	Vegetation surveys were conducted at each site by a private consultancy firm Species, growth form, vegetation height and soil samples were recorded at each site	January–February 2022	22–24 vegetation sample plots of 200 m^2 size were surveyed at each site. This was combined with complete mapping using aerial photographs and satellite imagery	Plant community classification from ordination analysis. The effect of environmental factors was quantified using canonical correspondence analysis. Lastly, the past and present land use from historical aerial images, plant species diversity, and vegetation sensitivity were combined to understand the sites' biodiversity value and characteristics	Unmanaged GI Assessing the biodiversity status of the sites' vegetation Findings integrated with stormwater assessment (in 3) as part of multifunctionality analyses (in 2)

Table 1 (continued)

	Methodological Approach	Method and instrument(s)	Sampling period(s)	Sample population and/or size	Data capturing and analyses	Focus and Integration
GI process & planning	**5. Policy document review**	Desktop review of policy documents that influence or impact GI spatial planning	Jan-May 2022	Snowball sampling of documents through expert consultation and webpage reviews 28 selected policy documents at national, provincial and municipal level	Inductive and deductive thematic analyses Identified planning principles present in documents. Considered whether these principles aligned with those from the literature. Cross-check for overlaps and differences	Managed and unmanaged GI Policy review: GI planning principles and policy gaps with **cross-sectoral implications** Findings integrated with interviews (in 6) and co-development workshops (in 8)
	6. Semi-structured interviews	In-person interviews Open-ended questions on: local definitions of GI; Challenges and opportunities in GI management	February and May 2022	Purposive and snowball sampling of 18 long-standing Tshwane metro officials Covering 7 Departments and units: City Sustainability, Economic Development and Spatial Planning, Environment and Agriculture Management, Community and Social Development Services, Human Settlements, and Roads and Transport	All interviews were recorded and transcribed with consent Inductive and deductive thematic coding and analyses in MS Excel	Managed and unmanaged GI **Public sector GI planning** opportunities and challenges Findings integrated with policy review (in 5) and co-development workshop (in 8)
Co-developing GI proposals	**7. Design studios**	Geospatial data, field observations on both sites, community verification through conversations and small workshops, review of municipal spatial planning proposals	April–May 2021; Aug-Sept 2021; Feb-April 2022	Four studios of 7 weeks each (two on each study site) Seven to 11 students per studio, delivering 23 booklets with design proposals and three Master theses design proposals	Data was captured in Epicollect, GIS mapping, AutoCAD and powerpoint Analyses of Strengths, Weaknesses, Opportunities and Threats (SWOT) for each study site and area GI design proposal development by students with review and input by the community, academics, consultants, specialists and metro officials	Unmanaged GI Design analyses and proposals to improve **local social access and socioeconomic needs** in balance with **ecological protection** and climate change mitigation Integrating social and ecological methods and findings from community survey (in 1) and multifunctionality assessment (in 2)

Table 1 (continued)

	Methodological Approach	Method and instrument(s) Sampling period(s)	Sample population and/or size	Data capturing and analyses	Focus and Integration
	8. Co-creation workshops	Two online and six in-person workshops with presentations, focus group discussions, plenary discussions, individual responses, pre-workshop questionnaires, etc • GRIP kick-off workshop, Online, April 13–14, 2021 • 2nd GRIP workshop, Online, Sept 9–10, 2021 • 3rd GRIP workshop Danish Embassy Pretoria, Oct 8, 2021 • GI Multifunctionality workshop, University of Pretoria (UP), 15 March 2022 • GRIP Planning Principles workshop, UP, 27 July 2022 • ILASA/ SAGIC seminar: GRIP findings, UP, 2 Nov 2022 • Seminar on design and justice, Danish Embassy Pretoria, 3 Nov, 2022 • GRIP final workshop, Online, 24 Feb, 2023	Eight workshops each between 15 and 50 purposively and snowball sampled participants including public sector, advisory experts, academics, students, private consultants/ practitioners	Note-taking, recordings, Delphi-based benefit weighting Inductive and deductive coding and thematic analyses	Managed and unmanaged GI **Transdisciplinary holistic understanding** of the existing and potential barriers and benefits of GI Integration of findings from methods 1–7 to guide local, context-specific, opportunities and to co-create proposals for GI multifunctionality improvements **across disciplines and sectors**

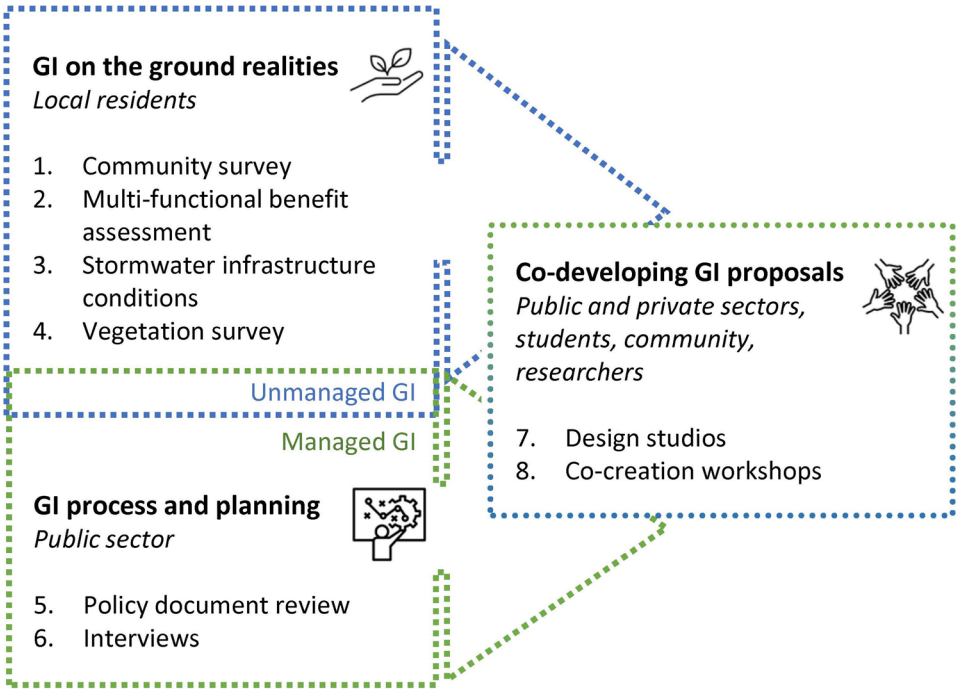


Fig. 2 Illustration of the three spheres of GI research with the eight methods to collect data from different perspectives to co-develop proposals

review; Pasgaard et al. 2023). These results show the unrealised potential within current communities to co-manage green spaces (see Fig. 5). As stated by this metro official: *"The city should not be seen as static. If we can increase access it's gonna help everything."*

In conclusion, we argue along with several stakeholders that GI opportunities include creating socioeconomic incentives for stronger human-nature relations, multifunctional benefit provision and greater care for GI in local communities across genders and generations (Pasgaard et al. 2023). Yet, the city requires proposals and strategies to achieve this, which is the real challenge as acknowledged by a practitioner: *"But that is one of the most difficult aspects because I mean, that specific integration aspect, that is getting everybody on board and buying into"*. In the next section, we move towards some proposals that flowed from the co-development workshops.

Proposals and discussion

Tshwane faces dynamic contextual challenges. Consequently, urban planning requires an emphasis on inclusive and adaptive environmental protection, multifunctionality, multiscaled approaches and safety in relation to GI (Breed et al. 2023). Co-development workshops with the public and private sectors identified opportunities for these objectives to manifest through collaborative governance, active

Fig. 3 Unmanaged green spaces are informal and unprotected, resulting in low levels of infrastructure to provide access, such as river crossings, and a lack of ownership that leads to littering, dumping and environmental degradation (photographs by Eyescapes 2021)

Fig. 4 Unmanaged green spaces become unappreciated unsafe no-man's-land, encouraging dumping. Informal uses are mostly passing through, but residents do use these spaces for a variety of activities (photographs by Eyescapes 2021)

citizenship, cross-sectoral partnerships and co-creating a joint vision for GI in the city (Breed et al. 2023).

Across sectors, GI must be considered equal to other infrastructure by effectively planning and costing for its inclusion. Due to the lack of results from static and conventional GI planning measures, the researchers advocate for flexible and creative alternatives that respond to the specific local scenarios exemplified below. For Tshwane (and likely beyond), five locally adapted planning principles are proposed to enhance GI.

Protecting GI by engaging with it

The current degradation of green spaces due to a perceived lack of ownership requires action. For example, environmentally safe recycling activities or small-scale trading must be encouraged and supported to discourage the current littering and dumping of waste in unmanaged green spaces. Rehabilitation and restoration activities are required, such as the removal of alien invasive species and the reintroduction of natural disturbance regimes (Buisson et al. 2022). Community actions to restore degraded areas can also restore the connection between urban residents and nature (Pasgaard et al. 2023). These socioeconomic activities can generate nature-based income and other informal uses (see Fig. 6), such as pocket parks, small leisure resorts and urban gardening, resulting in an incentivised basis for co-ownership and care that preserves green spaces for different activities and uses. Urban dwellers and development priorities compete for green space (Cocks et al. 2016; Takyi et al. 2022). Therefore, the careful cross-sectoral co-development of policies is required to formalise and legalise activities to enhance GI locally.

Supporting multiscale GI integration

Green infrastructure's spatial planning can increase network connectivity and build fabric integration that mediates habitat fragmentation and improves access to green spaces. This integration and increased connectivity include establishing green–blue corridors for plant and animal dispersal, combined with non-motorised transport routes for people to commute while appreciating contact with nature (see Fig. 7).

Encouraging multifunctional, safe and flexible GI

An important part of increasing GI's multifunctionality is conserving existing natural environments to prevent habitat loss and ensure green space provision and climate change benefits, such as mitigating flooding and the urban heat island effect. In light of climate change predictions for South Africa, which outline a future with a higher risk of the urban heat island effect and severe flooding (Engelbrecht 2019), urban green spaces can be a part of nature-based solutions and increase resilience, making their protection and optimisation for multifunctionality an urgent matter.

Fig. 5 The local communities were eager to engage with students but lack opportunities, initiative and support for greater involvement in their surrounding GI (photographs by Author 2022)

Fig. 6 Existing informal (and illegal) ways of communities co-managing and benefiting from unmanaged GI (photographs by Author 2022)

The use and overexploitation of GI can be a problem. In SSA many people perceive green spaces as vacant or unused land that has a better use (Guenat et al. 2020). However, as illustrated in the findings, trade-offs are required between conservation efforts and community access to GI benefits for socioeconomic needs. Green infrastructure access and use are important to ascertain its ownership and upkeep (see Fig. 8). This could be achieved by anchoring GI use through community initiatives and including educational activities for youths, strengthening social connectivity and appreciation of nature through enhanced ownership and care, as further elaborated below.

Creating opportunities for GI access and co-ownership

Physical access can be improved through landscape design that specifically targets access, diversifies use and increases safety through sight lines and surveillance. Titz and Chiotha (2019) advocate that access to and the use of GI enables urban inhabitants to become active, and produce and manage space for themselves. In South Africa and elsewhere, there is still a need for access considerations to be broadened to explicitly embrace both spatial and sociopolitical barriers that shape people's abilities to benefit from GI (Paganini and Lemke 2020; see Ribot and Peluso 2003). Unless equity and ownership concerns receive merited attention, safety and protection will remain important priorities for GI planning.

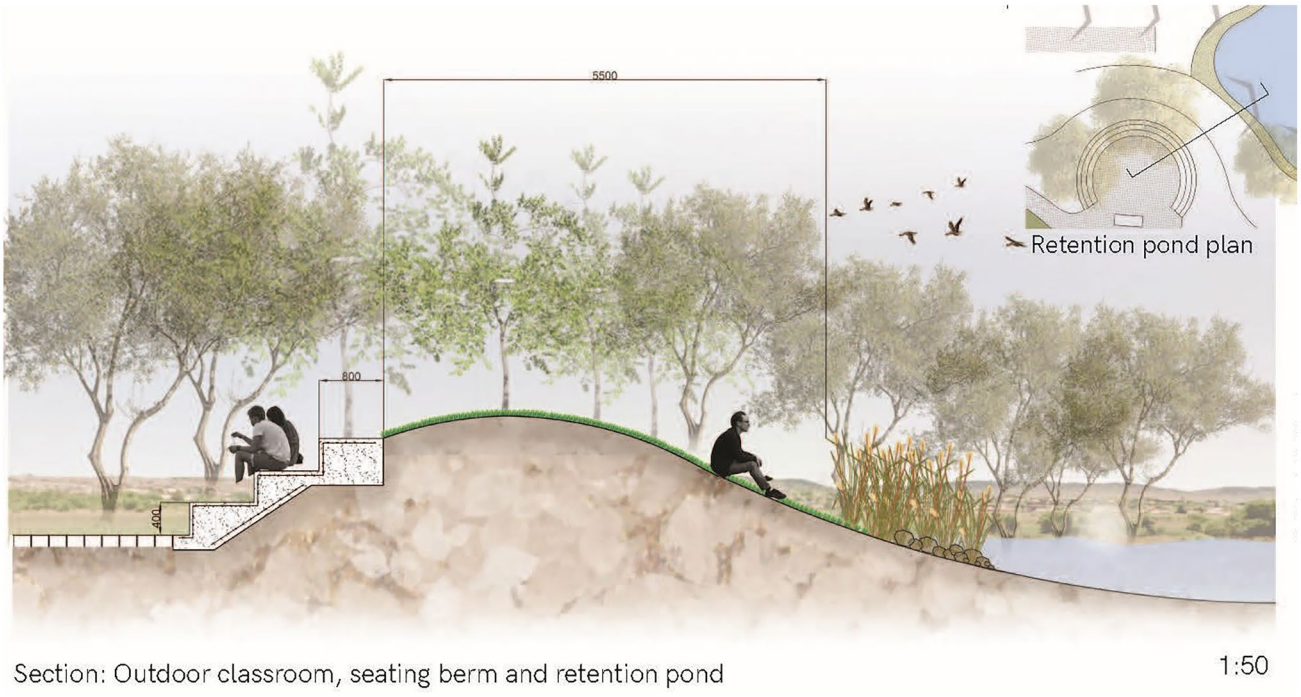
Design that effectively removes the barriers that limit social access must go beyond safety measures to include knowledge co-creation campaigns for sustainable use, inclusion in co-design processes, joint management and maintenance activities, and supporting local non-governmental organisations. Green infrastructure that does not meet the requirements of the different stakeholders of urban society can intensify social inequalities and disparities rather than promote social cohesion (Titz and Chiotha 2019). Awareness and appreciation of GI can be increased by anchoring design in local identity (Cocks et al. 2016).

Fig. 7 Green infrastructure networks, need to be connected and integrated into the city fabric at multiple scales, from pocket parks to larger parks, river systems and nature reserves (image by D Scoulund 2023)

Strengthening collaborative governance with cross-sectoral partnerships

A collective GI vision should cut across sectors and connect stakeholders, including concrete, feasible steps and actionable guidelines to improve urban GI. Benefit provision and access can be enhanced through strategic and inclusive planning and design that builds upon trans- and interdisciplinary collaboration and green space co-management (Roux et al. 2017). Such collaborative cross-sectoral decision making allows the inclusion of people with different perspectives, skills, expertise and training (Ogu 2000; Roux et al. 2017). The follow-through requires the co-development process to continue, and to be anchored and embedded in the metro (Wolfram et al. 2019).

Design initiatives must involve the relevant municipal departments. They must also explicitly address a targeted community, and consider how they can be involved



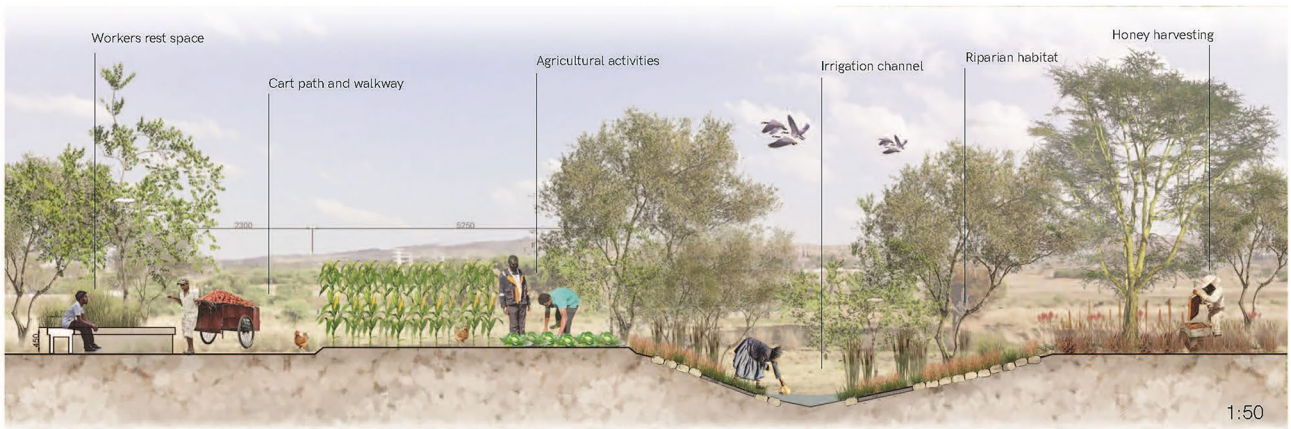


Fig. 8 Student proposals of community access and benefits that can lead to co-management and care of current unmanaged and unkept green spaces (images by C Mackenzie 2021)

throughout the design and management process. At the community level, Roy et al. (2018) advocate for an inclusive and creative form of urban planning, building on communities' inherent local knowledge and innovative power. Effective participation transcends the contribution of ideas and consensus moulding, and involves issues like empowerment and instilling a sense of care and ownership (Halla 1994).

Conclusion

The GRIP research project took some first steps towards confronting sustainable urban development challenges with a focus on GI in Tshwane. The researchers anticipate that the capacities and knowledge resources that are strengthened through the research described here can facilitate transformative changes from the political to the community level. At the metro level, the researchers engaged in planning and management by proposing and integrating GI guiding principles, while a remote sensing and GI decision-support tool was developed to alleviate technical capacities. The project improved the aptitude of students and researchers to grapple with multifaceted GI design and planning problems, whereas engagement and creative outreach projects spoke to local capacities. GRIP also effectively expanded environmental potential by shedding light on GI benefits and existing access constraints, which could assist with future risk management.

This research is further developed through the project Collaboration on Nature-based Solutions for Sustainable Cities (CONSUS), which will explore the potential for nature-based GI benefits through pilot projects that identify gaps in existing procedures and opportunities for synergies and mutual attainment. Critical aspects such as training in engagement strategies and community-based monitoring and management are at the venture's core.

Author contributions All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by all three authors. The first draft of the manuscript was written by Christina Breed, who also integrated the responses to the reviewers and all visualisations. All authors commented on previous versions of the manuscript and read and approved the final manuscript.

Funding Open access funding provided by University of Pretoria. This research was funded by the Danish Funding Agency under the Danish Ministry of Foreign Affairs, Integrative Green Infrastructure Project (GRIP), 2021 – 2023, Grant Number 20-M09AU.

Availability of data and material Data can be made available upon request from the first and corresponding author.

Declarations

Ethics approval Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Committee for Research Ethics and Integrity, Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria (reference number EBIT/45/2021, approved 18 April 2021); and the Director of Knowledge Management, City of Tshwane (approved 17 June 2021).

Informed consent All participants were informed about the purpose of the study and possible means of dissemination of the results. Participation was voluntary, with consent and all participants remained anonymous.

Competing interests The authors declare no competing interests.

References

Baruah NG, Henderson JV, Peng C (2021) Colonial legacies: Shaping African cities. J Econ Geogr 21(1):29–65. https://doi.org/10.1093/jeg/lbaa026

Barraclough AD, Cusens J, Måren IE (2022) Mapping stakeholder networks for the co-production of multiple ecosystem services: A novel mixed-methods approach. Ecosyst Serv 56:101461. https://doi.org/10.1016/j.ecoser.2022.101461

Breed C, Du Plessis M, Engemann K, Pauleit S, Pasgaard M (2023) Moving green infrastructure planning from theory to practice in sub-Saharan African cities requires collaborative operationalisation. Urban For Urban Green 128085. https://doi.org/10.1016/j.ufug.2023.128085

Breed C, Cilliers S, Fisher R (2015) Role of landscape designers in promoting a balanced approach to green infrastructure. J Urban Plan Dev 141(3). https://doi.org/10.1061/(ASCE)UP.1943-5444.0000248

Brom P, Engemann K, Breed C, Pasgaard M, Onaolapo T, Svenning J-C (2023) A decision support tool for green infrastructure planning in the face of rapid urbanisation. Land 12(2):415. Found online at https://www.mdpi.com/2073-445X/12/2/415. Accessed 10 Jul 2023

Buisson E, Archibald S, Fidelis A, Suding KN (2022) Ancient grasslands guide ambitious goals in grassland restoration. Science 377(6606):594–598. https://doi.org/10.1126/science.abo4605

Cilliers S, du Toit M, Cilliers J, Drewes E, Retief F (2014) Sustainable urban landscapes: South African perspectives on transdisciplinary possibilities. Landsc Urban Plan 125260–125270. https://doi.org/10.1016/j.landurbplan.2014.02.009

City of Tshwane (2020) City of Tshwane integrated development plan: Revision for 2020/21. Retrieved December 17 2022 from https://www.cogta.gov.za/cgta_2016/wp-content/uploads/2020/11/City-of-Tshwane-Approved-2020-2021-IDP-and-SDBIP-City-of-Tshwane-30-06-2020.pdf

Cobbinah PB, Nyame V (2021) A city on the edge: The political ecology of urban green space. Environ Urban 33(2). https://doi.org/10.1177/09562478211019836

Cocks M, Alexander J, Mogano L, Vetter S (2016) Ways of belonging: Meanings of "Nature" among Xhosa-speaking township residents in South Africa. J Ethnobiol 36(4):820–841

Du Toit MJ, Cilliers SS, Dallimer M, Goddard M, Guenat S, Cornelius SF (2018) Urban green infrastructure and ecosystem services in sub-Saharan Africa. Landsc Urban Plan 180:249–261. https://doi.org/10.1016/j.landurbplan.2018.06.001

Engelbrecht F (2019) Green Book – Detailed projections of future climate change over South Africa. Technical report, Pretoria: CSIR. Found online at: https://pta-gis-2-web1.csir.co.za/portal/sharing/rest/content/items/718369b1f453455e8febdf4f25f68249/data. Accessed 12 Jul 2023

Engemann K, Breed C, Brom P, Pasgaard M (in review) Transdisciplinary approaches to assess multifunctionality from unmanaged urban green spaces show benefits for biodiversity and people in City of Tshwane, South Africa. Plants Nat

European Commission (2013) Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions. Green Infrastructure (GI) – Enhancing Europe's Natural Capital. COM (2013) 249 final. Found online at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52013DC0249. Accessed 15 Jul 2023

Girma Y, Terefe H, Pauleit S (2019) Urban green spaces use and management in rapidly urbanizing countries: The case of emerging towns of Oromia special zone surrounding Finfinne. Ethiopia Urban for Urban Green 43:126357. https://doi.org/10.1016/j.ufug.2019.05.019

Guenat S, Dougill AJ, Dallimer M (2020) Social network analysis reveals a lack of support for greenspace conservation. Landsc Urban Plan 204. https://doi.org/10.1016/j.landurbplan.2020.103928

Halla F (1994) A coordinating and participatory approach to managing cities: The case of the Sustainable Dar es Salaam Project in Tanzania. Habitat Int 18(3):19–31

Landman K (2019) Evolving public space in South Africa: Towards regenerative space in the post-apartheid city. Routledge, New York, NY

Lurdes E, Pedrosa J, Okyere SA, Kusi Frimpong L, Diko SK, Commodore TS, Kita M (2021) Planning for informal urban green spaces in African cities: Children's perception and use in peri-urban areas of Luanda. Angola Urban Sci 5(3):50. https://doi.org/10.3390/URBANSCI5030050

Ogu VI (2000) Stakeholders' partnership approach to infrastructure provision and management in developing world cities: Lessons from the Sustainable Ibadan project. Habitat Int 24(4):517–533. https://doi.org/10.1016/s0197-3975(00)00015-1

Paganini N, Lemke S (2020) "There is food we deserve, and there is food we do not deserve": Food injustice, place and power in urban agriculture in Cape Town and Maputo. Local Environ 25(11–12):1000–1020. https://doi.org/10.1080/13549839.2020.1853081

Pasgaard M, Breed C, Heines ME, Knudsen L, Brom P, Schmidt A, Engemann K (2023) Citizen science beyond science A. collaborative approach for transformative sustainable development. Citiz Sci: Theory Pract 8(1):41. https://doi.org/10.5334/cstp.574

Pauleit S, Vasquéz A, Maruthaveeran S, Liu L, Cilliers SS (2021) Urban green infrastructure in the Global South. In: Shackleton CM, Cilliers SS, Davoren E, Du Toit MJ (eds) Urban ecology in the Global South. Springer International Publishing, Cham

Pfab MF, Compaan PC, Whittington-Jones CA, Engelbrecht I, Dumalisile L, Mills L, West SD, Muller P, Masterson GPR, Nevhutalu LS, Holness SD, Hoare DB (2017) The Gauteng Conservation Plan: planning for biodiversity in a rapidly urbanising province. Bothalia 47(2):v47i1.2182

Ribot JC, Peluso NL (2003) A theory of access. Rural Sociol 68(2):153–181. https://doi.org/10.1111/j.1549-0831.2003.tb00133.x

Roux DJ, Nel JL, Cundill G, O'Farrell P, Fabricius C (2017) Transdisciplinary research for systemic change: Who to learn with, what to learn about and how to learn. Sustain Sci 12(5):711–726. https://doi.org/10.1007/s11625-017-0446-0

Roy M, Shemdoe R, Hulme D, Mwageni N, Gough A (2018) Climate change and declining levels of green structures: Life in informal settlements of Dar es Salaam, Tanzania. Landsc Urban Plan 180:282–293. https://doi.org/10.1016/j.landurbplan.2017.11.011

Rupprecht CDD, Byrne JA (2014) Informal urban greenspace: A typology and trilingual systematic review of its role for urban residents and trends in the literature. Urban For Urban Green 13(4):597–611. https://doi.org/10.1016/J.UFUG.2014.09.002

Takyi E, Mensah H, Aazore FK, Nalumu DJ, Abu J (2022) Understanding the urban planning-green space depletion nexus: Insights from the Kwabre East Municipality, Ghana. Urban Forum. https://doi.org/10.1007/s12132-022-09471-x

Titz A, Chiotha SS (2019) Pathways for sustainable and inclusive cities in Southern and Eastern Africa through urban green infrastructure? Sustainability 11(10). https://doi.org/10.3390/su11102729

Wolfram M, Borgström S, Farrelly M (2019) Urban transformative capacity: From concept to practice. Ambio 48(5):437–448. https://doi.org/10.1007/s13280-019-01169-y