Urban greening for climate resilient and sustainable cities: grand challenges and opportunities

frontiers | Frontiers in Sustainable Cities

TYPE Specialty Grand Challenge
PUBLISHED 30 April 2025
DOI 10.3389/frsc.2025.1595280

OPEN ACCESS

EDITED AND REVIEWED BY
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RECEIVED 17 March 2025
ACCEPTED 31 March 2025
PUBLISHED 30 April 2025

CITATION
Kumar P, Sahani J, Corada Perez K, Ahlawat A, Andrade MdF, Athanassiadou M, Cao S-J, Collins L, Dey S, Di Sabatino S, Halios CH, Harris F, Horton C, Inostroza L, Jones L, Rodding Kjeldsen T, McCallan B, McNabola A, Kumar Mishra R, Kumar Mishra S, Sperandio Nascimento EG, Owen G, Ravindra K, Reis NC, Soebarto V, Wenk J, Wood HS and Yao R (2025) Urban greening for climate resilient and sustainable cities: grand challenges and opportunities.
Front. Sustain. Cities 7:1595280.
doi: 10.3389/frsc.2025.1595280

Urban greening for climate resilient and sustainable cities: grand challenges and opportunities

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KEYWORDS

urban greening, climate adaptation, UN SDGs, green infrastructure, strategic urban planning

Highlights

- Urban greening can improve air quality, health, biodiversity, and climate resilience.
- Collaboration among communities and stakeholders is key to urban greening success.
- Community engagement ensures acceptance and long-term success of green infrastructure.
- Barriers like funding, regulations, and resistance impede green infrastructure projects.
- Accurate data and planning are essential for maximizing green infrastructure benefits.

Urban greening plays a crucial role in enhancing climate resilience, environmental quality, public health, and societal wellbeing. Policy makers at all levels are increasingly embracing greening and other nature-based solutions; however, successful implementation of these approaches requires a multidisciplinary strategy involving collaboration, community engagement, and adaptive interventions. This paper synthesizes key insights from an expert panel, comprising representatives of government agencies, research institutions, private sector, and local authorities, forming an international panel of experts, convened by the RECLAIM Network Plus (https://www.reclaim-network.org). Funded by the United Kingdom Research and Innovation (UKRI), this network project brings together over 650 members from 40 plus countries. It provides national leadership in urban greening, serving as a "one-stop-shop" for towns and cities to access green and blue infrastructure support, resources, and peer connections. The paper highlights grand challenges, priorities, successful case studies and opportunities in urban greening initiatives. The importance of strategic planning is also addressed, together with technological advancements and access to suitable data for maximizing the impact of green infrastructure as well as innovative funding models, such as corporate social responsibility and green finance. This work highlights the importance of an integrated, inclusive, and forward-thinking approach to urban greening for more resilient, sustainable, and equitable cities. Further, it emphasizes the need for cross-sector collaboration among local authorities, researchers, and businesses, as well as community involvement in successful planning for both short- and long-term outcomes. Ultimately, urban greening strategies must be informed by future climate scenarios while prioritizing equity and social justice to ensure adaptation options benefitting all communities.

1 The role of urban greening in climate resilience and liveability

Urban greening, encompassing nature-based solutions (NbS) and green-blue-gray infrastructure (GBGI), has emerged as a vital strategy for building climate-resilient and livable cities, addressing biodiversity loss, and supporting Sustainable Development Goals (SDGs) (Wang et al., 2023; Kumar, 2021; Jones et al., 2022a). As urban populations continue to grow and climate change intensifies, urban communities worldwide are facing environmental challenges, including extreme heat, increased flooding, deteriorating air quality, noise pollution and biodiversity loss. Effective integration of urban greening—incorporating street trees, parks, urban forests, wetlands, green roofs and green walls, and permeable surfaces (Kumar et al., 2024a,b)—contributes to enhancing environmental sustainability and public wellbeing (Astell-Burt and Feng, 2019). One of the most critical roles of urban greening is its contribution to climate resilience. Cities experience the urban heat island (UHI) effect, where built-up areas absorb and retain heat, leading to higher temperatures compared to surrounding rural areas (Oke, 1982; Yang et al., 2024). Urban greening helps mitigate this phenomenon by providing shade, cooling through evapotranspiration, and reducing heat absorption. Green spaces, such as parks, tree-lined streets, and gardens, can significantly lower local temperatures, making cities more comfortable spaces, while also reducing energy demand and mitigating heat emissions from cooling systems (Yang et al., 2024; Kumar et al., 2024b). Unlike gray infrastructure, NbS do not further exacerbate the root causes of climate change through reliance on emissions-intensive products such as concrete. The cooling effect of vegetation becomes even more crucial during heatwaves, which are becoming more frequent due to climate change. By incorporating greening, cities can help mitigate heat-related illnesses, reduce strain on healthcare systems, and help prevent heat-induced impacts on worker productivity (Jones et al., 2024). Beyond temperature regulation, integrating blue (water bodies) and green (vegetation) elements with gray infrastructure enables cities to develop more holistic and sustainable flood management strategies compared to the traditional drainage systems. While impervious surfaces in cities prevent rainwater from naturally soaking into the ground, leading to increased runoff and urban flooding (Redfern et al., 2016), GBGI and Sustainable Drainage Systems (SuDS) offer effective solutions (Vesuviano et al., 2025). By mimicking natural water cycles, GBGI and SuDS not only reduce flood risk but also improve water quality, replenish groundwater reserves, and prevent polluted stormwater overflow that can contaminate natural waterways and compromise vital ecosystems (Monachese et al., 2025). GBGI and SuDS also serve functional purposes besides significantly enhancing the aesthetic quality of urban environments. The presence of green spaces and water features has been demonstrated to contribute to recreational opportunities, aesthetic enjoyment, and the overall wellbeing of urban residents (Johnson and Geisendorf, 2022). Furthermore, these systems can serve as educational opportunities concerning water management and environmental stewardship (Well and Ludwig, 2022). Finally, integrating NbS, such as reforestation for slope stabilization, into urban planning enhances climate resilience by mitigating landslide risks. Integrating NbS into conventional risk reduction infrastructure can significantly enhance public wellbeing and promote long-term sustainability (Alcántara-Ayala, 2025; Devanand et al., 2023).

Urban greening offers significant advantages in improving air quality (Abhijith et al., 2017; Islam A. et al., 2024; Kaur et al., 2025). Trees and vegetation function as natural air purifiers, efficiently capturing airborne pollutants such as particulate matter (Kumar et al., 2024a). In heavily polluted urban areas, a well-designed urban greening strategy can lead to significant health benefits, including reduced respiratory illnesses, improved public health and lower healthcare costs (Mueller et al., 2022; Jones et al., 2019; Nemitz et al., 2020). Beyond improving local air quality, urban greening reduces atmospheric concentrations of carbon dioxide through carbon sequestration (Page et al., 2021). However, some challenges remain in balancing NbS implementation to avoid hindering the vertical dispersion of air pollution emitted at ground level, such as the case of avenue planted trees in deep street canyons (Buccolieri et al., 2009; Abhijith et al., 2017; Kumar et al., 2019a).

Urban greening initiatives contribute to biodiversity conservation while concurrently enhancing environmental stewardship among urban populations (Roslund et al., 2021; Prescott et al., 2016). The integration of fragmented urban green spaces like urban forests, wetlands, and community gardens provides crucial habitats for diverse wildlife, promotes ecological balance, and ensures essential services such as pollination and pest control (Bowler et al., 2025; Dainese et al., 2019). While the Intergovernmental Panel on Climate Change recommends 30%–50% natural reserves globally to facilitate the natural recovery of terrestrial and marine ecosystems (IPCC, 2023), urban greening could partially contribute to this aim by connecting fragmented spaces in urban areas, thus supporting broader conservation efforts.

Beyond its environmental benefits, urban greening plays a vital role in improving social wellbeing (Kumar et al., 2019b). Green spaces provide residents with accessible opportunities for recreation, relaxation, and exercise in nature, leading to improved physical and mental health. Access to these areas has been shown to reduce stress, anxiety, and depression (Cohen-Cline et al., 2015), while encouraging physical activity and social interaction (Pretty and Barton, 2020; Pretty et al., 2003). Urban parks, community gardens, and tree-lined streets foster social cohesion by providing gathering spaces for diverse communities. Specifically, in high-density urban areas, small interventions such as green walls, green gates or pocket parks can substantially improve residents' quality of life (Abhijith et al., 2025; Kumar et al., 2024a). Despite the many beneficial aspects of NbS, several challenges remain in their implementation, as discussed in Sections 2–4.

2 Evolution of urban greening: past, present, and future

2.1 The past: an evolution of urban greening

Urban development has undergone significant transformations over the centuries, driven by industrialization, technological advancements, and changing social and economic conditions, among other factors. In Europe, the Roman concept of "*rus in urbe*," or countryside created within a building or city, was an early integration of natural landscapes into urban environments. In South Asia, the ancient towns in the Indus Valley in the Indian subcontinent exemplify early urban planning incorporating nature (Gregory, 2008). This includes traditional water harvesting structures and sustainable water management (Sharma, 2006). Mesopotamian and Persian civilizations notably exemplified by Persian gardens from sixth century BC Achaemenid dynasty, integrated green spaces into their landscapes for aesthetic, climatic and spiritual purposes, often representing paradise (UNESCO World Heritage Centre, 2025). Early advancements in urban sanitation infrastructure were excavated at Mohenjo-daro (2600–1800 BC) in present-day Pakistan (Jansen, 1985). Pre-industrial green spaces in Europe were often tied to aristocratic estates, religious institutions, or communal lands, such as Paris' Luxembourg Gardens established in the early seventeenth century and London's 142-hectare Hyde Park, established in the sixteenth century, which was initially developed for private hunting purposes (Self, 2014) before it was opened to the public in the following century (Porter, 1995). The gardens of Schönbrunn Palace is another example of an early urban green space, dating back to the fourteenth century, originally planned as a hunting ground, and later opened for public usage in the eighteenth century (Schönbrunn, 2025).

Rapid urbanization during the Industrial Revolution led to the widespread replacement of natural landscapes with gray infrastructure: roads, buildings, and engineered drainage systems. While this contributed to economic development, it also resulted in significant environmental challenges, including air and water pollution, UHI, and the loss of green spaces. Some cities developed public parks as an attempt to address overcrowding and poor living conditions, including New York's Central Park and Sefton Park in Liverpool. There are also many historic examples of the recognition of the benefits of green pockets for the health and wellbeing of the local community, in smaller cities and towns. One such example is the 4 acres of St Thomas Leisure Ground in Exeter, opened on 30th March 1891 for Queen Victoria's Jubilee, at the instigation of the Local Board of Health (Devon Gardens Trust, 2025).

In the early twentieth century, the Garden City movement advocated for the integration of green elements within planned urban developments, such as green belts and parks (Howard, 1902). At the same time, many Western cities underwent a transition toward a car-centric urban development model as automobile ownership rates increased. In the United States, car registrations tripled from 8 million to 26 million between 1920 and 1930 (Gavanas, 2024). This resulted in urban sprawl, with many cities expanding their road networks significantly by the 1950s (Barrington-Leigh and Millard-Ball, 2015). Initiatives to rebalance rapid urbanization with ecological stewardship followed (Mumford, 1938). The 1960s and 1970s brought a renewed focus on urban greening, driven by environmental concerns, the degradation of urban environments and legislative pressure, including the establishment in the USA of the U.S. Environmental Protection Agency in 1970 and the passage of the Clean Air Act and Clean Water Act. A significant shift in urban planning philosophy manifested advocating for the integration of natural systems and a closer collaboration between urban designers and scientists (McHarg, 1969). The eco-urbanism movement of the 1980s put a renewed focus on nature as greening, and the 1990s to early 2000s brought growing concern over human and urban pressures on ecosystems, with the emerging concepts of green infrastructure and ecosystem services (Di Marino et al., 2023).

Today, over three-quarters of global cities have adopted urban greening policies, integrating sustainability with urban growth (Khamdamov and Usmanov, 2024). As cities worldwide grapple with the challenges of climate change, pollution, and declining biodiversity, urban greening has emerged as a key strategy for building urban resilience and enhancing liveability. Studies show that greater green space availability is associated with better health outcomes such as lower mortality rates and improved mental health and sleep quality (Galitskaya et al., 2024). A green coverage between 10% and 20% has shown measurable health advantages (Nieuwenhuijsen et al., 2017). Neighborhoods maintaining at least 30% tree canopy coverage demonstrate significant improvements in mental, physical, and social health, as emphasized by the "3–30–300 rule" (Konijnendijk, 2023). The 3–30–300 rule offers clear urban greening guidelines, setting three minimum standards: (i) every citizen should be able to see at least three trees from their home, (ii) their neighborhood should have 30% tree canopy cover; and (iii) they should not live more than 300 m away from the nearest public park or green space.

2.2 The present: a new understanding of urban greening

In recent decades, urban greening has gained significant recognition for its importance for people's wellbeing, improving quality of life, and building sustainable cities (Di Marino et al., 2023). As topics such as climate resilience, environmental justice, and community engagement have become more prominent within built environment discourse, urban greening has emerged as a core element of sustainable and resilient urban planning. Urban planners and policymakers have embraced this concept, incorporating GBGI and NbS into their strategies, with GBGI exemplifying a multifunctional approach by integrating vegetation, water bodies, and built environment elements to create sustainable urban spaces.

Today, over 130 countries have incorporated NbS actions in their nationally determined SDG contributions, complementing technology-based solutions, including in urban contexts (IUCN, 2016). In relation to this, the International Union for Conservation of Nature and Natural Resources's Global Standard for NbS consolidates ecosystem-based approaches aligning urban greening strategies with SDGs (IUCN, 2020).

Various urban greening initiatives worldwide are aiming to address climate risks, SDGs, improving public health, and enhancing ecological sustainability. Examples are presented in chronological order of references:

- **Copenhagen's Cloudburst Management Plan**: A city-wide strategy designed to manage extreme rainfall events through the use of green roofs, permeable surfaces, and green corridors, which also enhances urban aesthetics and air quality (The City of Copenhagen, 2012).
- **UK's 25-Year Environment Plan, A Green Future**: This plan promotes biodiversity net gain (BNG) and SuDS to integrate water-sensitive urban design into city landscapes [Department for Environment, Food and Rural Affairs (DEFRA), 2018].
- **Indian Government's Sustainable Development Goals and Urban Local Bodies**: This guidance proposes key indices to promote and monitor sustainable urban stormwater management practices, aiming to enhance flood resilience and ensure effective drainage solutions in new developments (Government of India, 2018).
- **Welsh Government's National Standards for SuDS (2018)**: These standards require new developments of more than one dwelling or where an area covered by construction work equals or exceeds 100 m^2 to include SuDS features that comply with national standards (Welsh Government, 2018).
- **Natural England's Green Infrastructure Framework (2023)**: This tool highlights the institutional push for increasing green cover in urban residential areas, with an ambitious target of achieving 40% green cover in cities (Natural England, 2023).
- **South Australia's Long-Term Vision**: The State Government has created a vision for "a resilient and liveable Adelaide for all: cooler, leafier, and more biodiverse," setting priority actions for greener infill development and improving greening equity (Government of South Australia, 2024).
- **Singapore's City in Nature Plan**: This initiative aims to increase urban greening while promoting biodiversity conservation (Government of Singapore, 2025).
- **UKRI's Tomorrow's Engineering Research Challenges**: This strategic initiative by the umbrella UK science funding body prioritizes green materials and environmentally conscious engineering practices, aiming for engineering advancements that positively contribute to the planet (EPSRC, 2025).

Collectively, such initiatives highlight a fundamental shift in urban planning, where green spaces are not seen as mere decorative elements but as crucial infrastructure for resilience and wellbeing. Cities worldwide are adopting innovative solutions to address urban challenges, including the integration of green roofs and vertical gardens, in the context of urban resilience and adaptation planning (Saqib et al., 2024).

2.3 Future directions: technology-driven and inclusive urban greening

Urban greening is expected to become increasingly data-driven, leveraging technologies such as Geographic Information Systems (GIS), artificial intelligence (AI), and remote sensing to optimize the design and management of green infrastructure (Stessens et al., 2021; Rahmati, 2024). These tools will enable built environment professionals (e.g., landscape architects, developers, city planners) to more effectively assess environmental needs, target adaptation options, model the impact of greening interventions, and monitor the effectiveness of urban green spaces in a holistic way. Future urban greening will integrate Internet of Things (IoT), AI, and real-time analytics for smart water management, optimizing flow, and drainage efficiency (Langenheim et al., 2022). Digital twin technology and AI-driven planning will enable real-time simulations and optimized GBGI and SuDS (Dembski et al., 2020; Xu et al., 2024). Advanced permeable pavements and bioengineered materials will enhance infiltration and pollutant filtration, leveraging nanotechnology for contaminant absorption (Verma et al., 2024). In addition to technologically driven future approaches, there is also an increasing emphasis on citizen/community engagement in urban planning processes, however addressing structural barriers and ensuring meaningful participation remain ongoing challenges (Sondou et al., 2025).

Green finance, corporate sustainability and decision-making processes that are informed by a comprehensive economic valuation of the net benefits of urban greening (including its environmental, social, and health benefits), are also expected to play an important role in shaping the next phase of urban greening (Williams et al., 2025; Tefera et al., 2023). Policies promoting investment in green bonds, environmental, social, and governance (ESG) frameworks, and public–private partnerships are expected to accelerate large-scale greening projects. Additionally, smaller-scale community-led urban greening initiatives will be vital to ensuring that cities remain inclusive, mitigating the risk of "green gentrification," where the introduction of urban green spaces inadvertently displaces low-income residents due to rising property values.

Finally, as climate change intensifies, urban greening strategies will need to be resilient and adaptive. Cities will need to focus on climate-resilient landscaping considering their micro-climatic conditions, for example, selecting appropriate drought-resistant plant species, water-sensitive urban designs, and ecological corridors that promote biodiversity. Urban agriculture, vertical gardens or farms, and rooftop farms are also expected to gain prominence, addressing both food security and environmental sustainability in growing urban populations (Drottberger et al., 2023).

3 Best practice in urban greening

Urban areas worldwide have implemented innovative greening projects that serve as effective models for sustainable development. Inspiring case studies showcasing tangible benefits and strategies have emerged from urban greening initiatives, with platforms like the Urban Nature Atlas compiling best practices globally, as does the NbS Initiative's approach for rural areas (Urban Nature Atlas, 2025; Nature-based Solutions Initiative, 2025; Debele et al., 2023). Analyzing these case studies is crucial for understanding effective strategies, benefits, and lessons learned in urban greening, informing future urban planning and sustainability efforts.

3.1 Selected case studies

The following curated selection of 10 case studies, presented in alphabetical order of the name of city, has been drawn from authors' recommendations and discussions at the RECLAIM Network Plus Conference (http://www.reclaim-network.org):

1. Adelaide, South Australia has unveiled a street tree planting plan to increase canopy cover from 33% to 40% by 2035, complemented by green infrastructure initiatives like water-sensitive urban design (City of Adelaide., 2024). Similarly, Melbourne, Victoria, has implemented the Urban Forest Strategy 2021–2032, aiming for a "resilient, healthy, and diverse" urban environment. This strategy targets increasing tree canopy cover from 22% to 40% by 2040, while also focusing on urban forest diversity, vegetation health, soil moisture, water quality, and biodiversity enhancement (City of Melbourne., 2021).
2. Brazil's Ministry of the Environment initiated the Cidades+Verdes Program (França and Ramos de Almeida, 2021) to enhance urban green areas, aiming to improve quality of life for 85% of Brazilians living in cities. The Urban Environmental Registry (CAU) was created to map and share information about these areas, allowing municipalities to register urban green spaces and citizens to access and evaluate them. Urban greening initiatives in Brazil largely focus on rain gardens to address frequent storms and flooding (ICLEI, 2025). Examples include: (1) Belo Horizonte, Minas Gerais, implemented three rain gardens to improve urban drainage; (2) Niterói, Rio de Janeiro: The Parque Orla Piratininga Alfredo Sirkis project, a 680,000 m^2 linear park along the P iratininga Lagoon, featuring 35,290 m^2 of filtering gardens to protect and restore local ecosystems; (3) São Paulo, São Paulo, installed rain gardens across the city to mitigate flooding during the rainy summer season; and (4) Curitiba, Paraná, launched the city's first Urban Farm in 2020, dedicating 4,000 m^2 to organic food production, with plans for an additional 11,000 m^2 unit. Other regions have also implemented green infrastructure, primarily for flood prevention. These efforts highlight Brazil's commitment to nature-based solutions, enhancing resilience and urban quality of life.
3. Cardiff, Wales, United Kingdom has launched an ambitious "*One Planet Strategy*" (Cardiff Council, 2020). This 10-year afforestation programme aims to support Cardiff to be a carbon neutral city by 2030, increasing green cover and promoting community engagement in sustainable development. Since its inception, the programme has planted over 82,000 trees across the city, emphasizing local community participation and encouraging residents to take ownership of green spaces. Cardiff Council, with Welsh Government funding, is developing flood risk reduction plans for Whitchurch Brook, a historically heavily modified local watercourse. This project combines green infrastructure with SuDS techniques to control surface water flow while improving public space areas. The project integrates green infrastructure and SuDS to manage surface water and enhance public spaces. Design and planning are being led by a sustainable development consultancy, with community input shaping the solutions (Cardiff News Room, 2023). This participatory approach has not only strengthened environmental stewardship but also fostered social cohesion, demonstrating that urban greening can be both an ecological and a social asset.
4. Copenhagen, Denmark has implemented green roof policies to improve building insulation, manage stormwater, and enhance urban biodiversity (City of Copenhagen., 2010; Ansel and Appl, 2025). While green roofs reduce buildings' energy consumption, ground-level greening offers greater social and environmental benefits in dense urban areas. The city now emphasizes street-level greenery like pocket parks, green walls, and community gardens. Copenhagen's Østerbro "Climate Quarter" exemplifies this approach, featuring urban greening projects that mitigate flood risks and improve public spaces, such as Sankt Kjeld's Square and Taasinge Plads (Larsen, 2018).
5. In Exeter, England, United Kingdom, the campus of the UK Met Office headquarters has earned a Biodiversity

Benchmark certificate (The Wildlife Trusts, 2025), highlighting its commitment to maintaining a rich ecological zone amid a developed area (Met Office, 2021, 2025a). The project includes pollinator-friendly meadows, water-efficient landscaping, and protected habitats for local wildlife. This initiative exemplifies how large organizations can incorporate biodiversity conservation into their urban footprint, serving as a model for businesses looking to integrate sustainability into their operations.

6. The Zero Carbon Initiative in Guildford, England, United Kingdom combines urban tree planting with SuDS to mitigate urban heat stress and manage stormwater (Zero Carbon Guildford, 2025) as well as installation of green screens and school living gate (Abhijith et al., 2025). The combination of these strategies exemplifies a holistic approach to urban greening, where multiple ecological and infrastructural benefits can be achieved simultaneously.
7. Nanjing, Jiangsu Province, China is home to the Vertical Forest project, an innovative urban afforestation initiative integrating nature-based solutions into architecture. This project features two towers in the Pukou District, standing at 200 and 108 m, with facades adorned by alternating balconies and greenery. Housing over 800 trees and 2,500 shrubs across 4,500 m^2, the design incorporates 27 native species. This approach enhances biodiversity, improves air quality, reduces surface temperatures, and regulates humidity, ultimately enhancing urban livability (Boeri Architetti, 2025).
8. New York City's MillionTreesNYC program, a landmark public–private partnership, aimed to plant one million trees across the city, focusing on underserved neighborhoods lacking green spaces (Fisher et al., 2014). Exceeding its goal ahead of schedule, the project demonstrated effective collaboration among government agencies, non-profits, and local communities. The success of MillionTreesNYC highlights the importance of long-term maintenance and community engagement in urban greening projects.
9. Singapore, a global leader in urban greening, has pioneered nature integration into its cityscape through the "City in Nature" plan. This initiative builds on decades of green infrastructure development, expanding tree-lined streets, rooftop gardens, and vertical greenery on high-rises (Government of Singapore, 2025). The city's green corridors connect parks and natural reserves, fostering wildlife and providing accessible green spaces for residents. Driven by strong government policies, technological innovation, and public–private collaboration, Singapore's approach exemplifies how urban greening can be seamlessly incorporated into high-density environments, balancing economic growth with ecological sustainability.
10. The Trees for Homes (TfH) programme in South Africa is an urban greening initiative promoting biodiversity enhancement and climate adaptation through household tree planting. The initiative was established around 1992 as a flagship urban greening initiative by the organization Food and Trees for Africa. In the Zandspruit neighborhood, the TfH project incorporated key sustainable livelihood principles, including being people-centered, responsive and participatory, multi-level, conducted in partnership, sustainable and dynamic. However, it was also noted that a key barrier to success in vulnerable communities was instability of tenure (Sachikonye et al., 2016). The TfH initiative has recently partnered with Johannesburg Inner City Partnership to train local environmental champions to act as Community Educators, who receive specialist training in climate change, tree care, environmental ethics, and community engagement.

3.2 Learning from successful urban greening projects

The 10 case studies of successful projects offer valuable lessons for enhancing urban living through NbS, highlighting the importance of active community involvement, integrated urban design, and long-term sustainability in creating climate-resilient urban spaces. Innovative approaches, including transforming existing buildings into green spaces, further demonstrate the potential for integrating nature into densely built environments. These successful strategies provide insights for cities worldwide to develop context-specific, innovative solutions for more climate-resilient urban spaces.

The longevity of well-designed green spaces is exemplified by the UK's urban parks, such as St. Thomas People's Park in Exeter, established in 1891 (Exeter Memories, 2009). Originally created as a safe space for children and vulnerable people, the park continues to serve the local community over a century later, underscoring the importance of sustainable design in GBGI projects.

Maximizing the public health benefits of GBGI projects requires effective cross-sector collaboration. In Surrey, efforts to integrate public health expertise into environmental initiatives have shown promise, with general practitioners engaging in discussions about air pollution and climate change (Zero Carbon Guildford, 2025). However, these efforts often remain isolated highlighting the need for greater coordination to address overarching priorities such as health inequalities and community empowerment.

To enhance GBGI project effectiveness, public health practitioners should be involved in co-creation and planning stages, while challenges persist, including limited financial and human resources. Research from Cardiff Council and Vale University Health Board area has revealed that air pollution disproportionately affects poorer areas (Cardiff Council, 2025), emphasizing the need to align GBGI projects with public health priorities. Overcoming these barriers requires a coordinated approach that integrates public health as a primary driver of greening initiatives, rather than a secondary co-benefit, ensuring that urban planning prioritizes both environmental and health outcomes.

4 Key challenges and strategic solutions for implementing urban greening

Urban greening initiatives, despite their well-documented benefits, face numerous challenges including financial and regulatory constraints, space limitations, impacts on the vertical dispersion of air pollution, maintenance issues, year-round effectiveness limitations due to climate variations and plant species types, lack of interdisciplinary collaboration, and resistance to innovation within established structures and processes (Grunewald et al., 2021; Haaland and van den Bosch, 2015). Overcoming these obstacles require supportive policies, innovative financing, technological advancements, and inclusive community engagement. Some of the key challenges and strategic solutions (Figure 1) are presented in subsequent sub-sections.

4.1 Financial constraints, sustainable funding, and economic value

Urban greening strategies, such as GBGI and NbS offer long-term economic benefits such as reduced healthcare costs, energy savings, and improved property values. However, high upfront costs for land acquisition, infrastructure development, maintenance and misconceptions deter both public and private investment (Riedman et al., 2022; Rowley et al., 2022). Municipal budgets are often stretched, and many greening initiatives rely on single-source or short-term funding, limiting their long-term viability (C40 Cities Climate Leadership Group, 2022).

Government budgets and grants typically cover only capital costs for urban greening projects, excluding or providing limited-term funding for ongoing maintenance and operational expenses only. Consequently, many projects face neglect due to insufficient resources for routine upkeep, resulting in degraded green spaces that fail to achieve their intended outcomes (Albro, 2020).

Establishing sustainable funding mechanisms, such as public-private partnerships, green bonds, and community-led stewardship programmes, can help address the challenge of maintaining urban greening over time (Nash et al., 2021). Importantly, green and surface-based climate adaptations are likely cheaper to implement than large traditional gray infrastructure projects like sewer expansions (Xu et al., 2021). To encourage continuing public investment, it is crucial to demonstrate the financial rewards of NbS, particularly in terms of climate change resilience for issues like flooding.

The health benefits associated with NbS provide another compelling argument for urban greening initiatives, especially when addressing air quality and heat stress. While general wellbeing improvements may be subjective, quantifying health costs related to these issues and assessing potential cost reductions through environmental improvements can justify financial investments in urban greening. Techniques to quantify the economic value of ecosystem services provided by urban green infrastructure (Mell et al., 2016; Jones et al., 2019; Fletcher et al., 2021) can position these solutions as cost-effective approaches to building climate resilience, while offering a dual benefit of improved public health and enhanced urban sustainability (Elmqvist et al., 2015).

Innovative financing mechanisms can provide solutions to these challenges. For example, green bonds, corporate ESG funding, crowdfunding, and public–private partnerships (PPPs) offer possible solutions to ensure long-term investment. Green bonds provide a structured financial tool for municipalities and businesses to raise capital for environmental projects, while corporate ESG funding encourages businesses to invest in urban greening as part of their sustainability commitments. In particular, PPPs can help to distribute financial risk while leveraging private sector efficiency and public sector oversight (Naumann et al., 2011). Crowdfunding platforms raise small contributions for urban greening projects like tree planting and parks. Social impact funds and blended finance combine public, private, and philanthropic investments for social and environmental returns, as seen in the World Bank's Urban Resilience Fund (World Bank, 2015). Green Real Estate Investment Trusts (REITs) finance eco-friendly real estate with integrated green spaces (Hin Ho et al., 2013). Utility-backed financing reinvests savings from reduced water, energy, or stormwater costs into green infrastructure. Additionally, cities can introduce incentives such as tax breaks or subsidies for developers who incorporate greening elements into their projects. Establishing dedicated municipal budgets for urban greening and integrating it into broader urban resilience plans ensures that green infrastructure is not treated as an afterthought but as a critical component of sustainable city planning. Finally, training programs for local communities in green space management and ecological restoration can create job opportunities while fostering a culture of environmental stewardship.

Economic valuation is crucial for effective urban greening and management, requiring comprehensive decision-support tools that accurately assess both benefits and costs. Such tools can guide policymakers in determining optimal quantities, locations, and species of plants, while balancing urban greening with infrastructure development. Current frameworks fall short in capturing the full spectrum of benefits, including improved air quality, carbon storage, water management, energy efficiency, and public health (Tefera et al., 2023). Consequently, sustainable greening costs often seem to outweigh benefits, stemming from inadequate long-term benefit accounting, limited predictive modeling capabilities, and insufficient reliable data. Addressing these challenges is essential for making informed urban greening decisions that create more sustainable and liveable cities.

4.2 Regulatory and governance challenges

Fragmented governance structures, unclear policies, and bureaucratic delays hinder the planning and execution of urban greening projects. Multiple agencies, including local governments, urban planners, environmental departments, and private developers, often operate independently, leading to siloed decision-making and slow project approvals. For example, policies such as the UK's Greening Policy, which aims for 40% green cover in urban residential areas (Natural England, 2023), may struggle with enforcement due to the limited capacity of local authorities. Similarly, at the local scale, initiatives like the Guildford Borough Council's goal to double Biodiversity Net Gain (BNG) from the standard 10% to 20% encounter implementation challenges, as biodiversity policies are established at the county level but enforced by district and borough councils. Similar issues arise with other planning commitments, such as affordable housing and green infrastructure, which are often approved but not

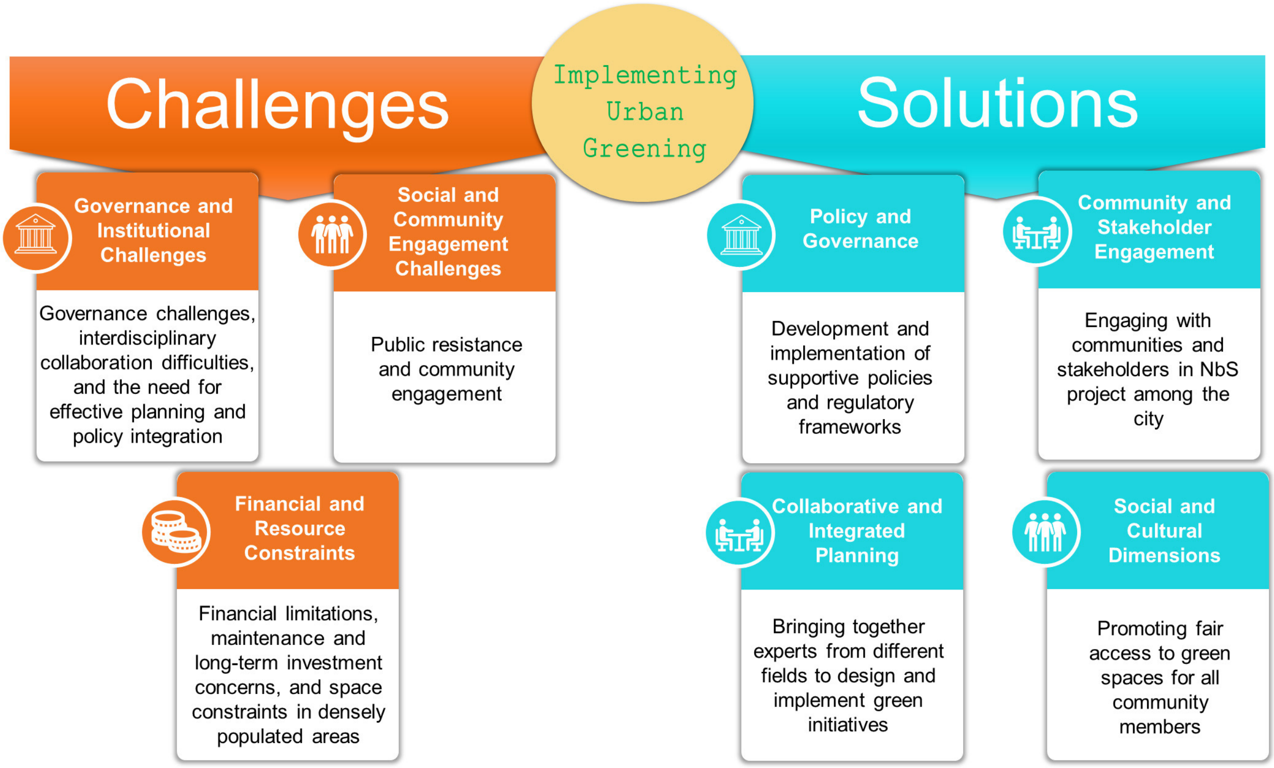

FIGURE 1
Challenges and solutions for implementing urban greening in cities. A summary of key barriers to urban greening, including limited land availability, high costs, regulatory constraints, and fragmented governance, alongside potential solutions such as multifunctional land use, streamlined policies, stakeholder collaboration, and innovative green infrastructure integration.

delivered due to cost and regulatory constraints. Addressing these challenges requires strategic planning, supportive policy frameworks, strengthening coordination among stakeholders, streamlining approval processes, and enhancing policy frameworks that actively promote urban greening.

Large city-scale urban greening should adopt agile management approaches that allow for flexibility and continuous improvement based on environmental and social feedback. Thus, urban greening should be embedded within broader climate adaptation plans to enhance resilience against environmental challenges such as heat waves, floods, and pollution. By aligning greening efforts with broader urban resilience strategies, cities can maximize the impact of adaptation options and ensure long-term sustainability. Governments should enforce green infrastructure requirements, such as BNG, green roofs, urban forests, and permeable surfaces in new developments. Strengthening urban greening legislation at national and local levels ensures that towns and cities can prioritize sustainable development over short-term economic gains.

Reducing bureaucratic delays and improving coordination between local governments, environmental agencies, and developers can accelerate project implementation. However, challenges in enforcing green infrastructure commitments can arise due to under-resourced planning departments. For instance, Surrey County Council, responsible for the local nature recovery strategy including a goal of planting 1.2 million trees, faced such difficulties in executing their green initiatives effectively (SCC, 2021).

4.3 Space constraints: balancing development and sustainability

Urban morphology plays a crucial role in determining the spatial extent and types of greening strategies that can be effectively implemented in cities (Owen et al., 2024; Kumar et al., 2024a,b). As urban areas expand, limited land availability forces green infrastructure to compete with development, making it crucial to plan ahead rather than retrofitting later. Existing urban structures, high costs, and regulatory barriers often constrain the implementation of green spaces, particularly when retrofitting developed areas. These challenges are compounded by the fact that stakeholders, such as shop owners and local communities, may have minimal influence over decisions regarding GBGI projects, especially in town centers.

To overcome these space constraints, urban planners must adopt innovative approaches and technologies. Integrating vertical gardens, rooftop gardens, green corridors, and pocket parks can maximize the use of limited space in developed areas. However, these solutions require strategic design to ensure they maximize ecological and social benefits without compromising urban functionality. Furthermore, urban planning strategies need to shift toward prioritizing multifunctional land use that balances development with environmental sustainability.

Effective implementation of GBGI solutions requires a holistic approach. This includes the ability to quantify the cost–benefit of green infrastructure compared to traditional gray solutions,

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considering both immediate and long-term impacts. Moreover, it is essential to incorporate the "voice" and needs of local communities in GBGI interventions, whether in existing urban areas or new developments. By involving stakeholders in the decision-making process and adopting innovative planning strategies, cities can more effectively address space constraints and create sustainable, liveable urban environments that benefit both residents and the ecosystem.

Regarding green space distribution, community engagement is crucial (Riedman et al., 2022). It ensures that the focus extends beyond merely achieving percentage targets of green area coverage in a given region. Instead, it emphasizes placing appropriate solutions in strategic locations. The physical impacts of green spaces are spatially linked, diminishing with distance. Solely examining citywide percentages of green spaces may obscure the fact that benefits are not uniformly experienced across the entire urban landscape. Therefore, a targeted and communicative approach helps distribute benefits more effectively, particularly to disadvantaged communities.

4.4 Community engagement and public awareness campaigns

Community-driven initiatives, where residents are involved in the planning, maintenance, and stewardship of green spaces, can significantly enhance public support and project sustainability (Aslanoglu et al., 2025). Without proper engagement, communities may feel excluded from decision-making processes, leading to distrust and reluctance to support greening efforts. Additionally, in some cases residents and businesses may oppose greening projects due to misconceptions or factual concerns about land-use changes, maintenance responsibilities, and perceived inconveniences. These could be related with concerns about green gentrification, including increased property taxes, possibilities of fallen tree limbs, changes in neighborhood aesthetics and in traffic management; all these can potentially lead to opposition from local communities (Nobles and Moore, 2024; Meenar et al., 2022).

Effective community engagement involves transparent communication, co-creating projects with local residents, and addressing concerns about land use changes. Participatory decision-making processes, including town hall meetings, co-creation workshops, and citizen-led greening programs, empower communities to take ownership of green spaces. Public participation in tree planting, park maintenance, and urban gardening has been shown to foster a sense of ownership and encourages community stewardship of green spaces (e.g., Jennings et al., 2016; Bressane et al., 2024). This not only enhances public support for urban greening but also strengthens social cohesion and long-term stewardship of these spaces. The public can also actively participate in maintaining the green space, contributing to its design, and engaging in green space science outreach initiatives. Involving diverse stakeholders, such as local governments, non-profit organizations, and private developers, ensures that greening projects receive the necessary financial and logistical support while being aligned with broader urban development goals. The collaboration with communities in co-creating solutions is essential for reflecting the needs and preferences of local residents.

Educating citizens on the environmental and health benefits provided by urban greening features such as the green spaces further reinforce the importance of urban greening (Nguyen and Chidthaisong, 2024). Schools, workplaces, and community organizations can actively promote greening initiatives, emphasizing the role individuals can play in supporting these efforts (Zhang et al., 2024). Integration of urban greening into public health initiatives can also increase awareness of their benefits and encourage behavioral changes that support greener lifestyles and green social prescribing (Kruize et al., 2019). Governments and NGOs can leverage digital platforms, citizen science initiatives, social media, and interactive workshops to engage diverse audiences and inspire collective action through established behavior change levers that include identity-based social contagion, and the use of trusted messengers, normative appeals and "shared destiny narratives."

4.5 Equity and inclusivity in urban greening

Urban greening initiatives must prioritize equity and inclusivity to ensure fair distribution of benefits across all communities. Socially disadvantaged groups often face disproportionate environmental challenges, making equitable access to green infrastructure crucial (Hsu et al., 2022; Richards et al., 2023; Williams et al., 2025). To address this, there is a need for: (1) Ensuring that all communities, especially low-income and marginalized groups, benefit equally from improved air quality, cooling effects, and recreational opportunities; (2) Addressing disparities by recognizing that disadvantaged communities often suffer worse environmental consequences compared with more affluent areas, and tailor interventions accordingly; (3) Mitigating gentrification by implementing policies to prevent displacement and maintain affordable housing alongside greening projects; (4) Guiding urban greening efforts with social justice considerations to create healthier, more inclusive urban environments for all residents (Anguelovski and Corbera, 2023). By incorporating these principles, cities can develop urban greening strategies that not only improve environmental quality but also promote social equity and community wellbeing.

One of the major challenges of urban greening is the risk of green gentrification, where improved environmental quality leads to increased property values, ultimately displacing low-income residents (Jelks et al., 2021). While new parks, tree-lined streets, and urban forests enhance the overall liveability of a city, they can also attract wealthier residents and investors, making housing unaffordable for marginalized communities. To counter this, policymakers must integrate greening initiatives with affordable housing policies. Rent control measures, community land trusts, and mixed-income housing developments can help ensure that existing residents are not forced out due to rising costs. Additionally, designing green spaces that cater to diverse socio-economic groups, such as multipurpose parks, community gardens, and culturally relevant recreational areas, can promote inclusivity and prevent the exclusive transformation of neighborhoods. Implementing greening guidelines such as the 3–30–300 rule can help reduce inequity of access to greenspace, and thereby avoid green gentrification, although there are substantial challenges to retrospectively achieving these targets in densely built up cities (Owen et al., 2024). Nevertheless, it remains a valuable aspiration for cities wanting to increase their greenspace, especially in residential areas.

Ensuring urban greening aligns with social and environmental justice requires prioritizing communities that historically lack access to green spaces. Low-income neighborhoods, often characterized by limited tree cover and fewer parks, experience higher temperatures, greater vulnerability to disasters, increased air pollution, and lower overall wellbeing. Greening efforts should be directed toward these areas to reduce health disparities and improve climate resilience (Rigolon et al., 2021). Public health benefits, such as reduced heat-related illnesses, improved air quality, and enhanced mental wellbeing, should be central to urban greening policies. Moreover, incorporating climate justice principles, where the needs of vulnerable populations are at the forefront of urban planning, ensures that greening efforts do not disproportionately benefit affluent areas while neglecting marginalized communities.

Equitable urban greening also requires addressing intersectional issues, such as accessibility, safety, and cultural inclusivity (Endalew Terefe and Hou, 2024). Green spaces must be designed to accommodate people of all ages, abilities, and backgrounds. Features such as wheelchair-accessible paths, shaded rest areas, and appropriately-lit public parks improve accessibility and usability for all residents. Safety concerns, particularly in marginalized neighborhoods, should be addressed through community-led monitoring programs and strategic placement of greenery to avoid creating isolated areas. Furthermore, integrating cultural elements into green spaces, such as indigenous planting practices, spaces for traditional celebrations, and art installations reflecting local heritage, enhances community identity and encourages greater use of urban greening. Where minority communities feel a sense of belonging in a local greenspace, their experiences of greenspace are often very positive (Palmer et al., 2025).

4.6 Interdisciplinary collaboration for effective implementation

Effective GBGI design and implementation requires expertise from various fields, including urban planning, environmental science, engineering, architecture, public health, economics and social sciences (Butt and Dimitrijević, 2022). However, a lack of interdisciplinary coordination often results in disjointed efforts that fail to maximize the full potential of urban greening. For example, planners may focus on aesthetics, or succumb to pressures for more housing, without considering ecological benefits or giving ecological benefits less priority, while engineers may prioritize stormwater management, the landscape architect will value biodiversity conservation, and so on.

The diverse knowledge base required to deliver a comprehensive plan, points to the need of a project manager or other champion that is able to coordinate all the various parts into one harmonious whole (Figure 2). While ambitious targets for tree cover and green space exist, there is criticism that public health practitioners are not leading environmental and greening initiatives to the standards imposed e.g., by air pollution reduction goals. Local authorities acknowledge efforts to engage with health professionals but work often happens in silos due to resource constraints and lack of effective communications. Despite good research and monitoring, effective collaboration remains limited.

Public health should not just be a co-benefit but a driving force in greening strategies, especially as pollution and health inequalities are often concentrated in disadvantaged areas. Encouraging cross-sector collaboration, knowledge-sharing, and integrated planning approaches can lead to more holistic and effective urban greening solutions. By proactively addressing these challenges, cities can harness the full potential of green infrastructure to enhance climate resilience, biodiversity, and overall liveability for future generations.

Urban greening calls for stronger collaboration between networks to achieve ambitious targets such as 40% green cover in urban areas (Natural England, 2023). Bringing together experts from urban planning, climate science, ecology, public health, and civil engineering can help foster new and holistic solutions that address multiple urban challenges simultaneously. Considering the needs of people in greenspace planning also involves understanding how their needs change as they go about their lives in the city, locally where they live, but also where they work and travel in between. Concepts such as "people-sheds" help formalize these requirements (Jones et al., 2022b). Cities should create cross-sector partnerships among local governments, businesses, academic institutions, and non-governmental organizations (NGOs) to pool resources, knowledge, and expertise. Such collaborations can accelerate project implementation, enhance innovation, and ensure urban greening aligns with broader sustainability and resilience goals.

4.7 Leveraging technological advancements

Data-driven planning plays an important role in optimizing urban greening initiatives. Technologies such as Geographic Information System, Machine learning, artificial intelligence, and availability of suitable, spatially coherent data (remote sensing, aerial imagery or satellite photography), enable spatial risk assessments at unprecedented resolution, thus enabling identification of areas most in need of green infrastructure (Fletcher et al., 2021). By harnessing these new tools, urban planners can maximize the ecological and social benefits of green spaces while ensuring efficient resource allocation. AI techniques have been applied to optimize green-blue infrastructure for climate resilience, analyzing complex environmental data to improve the design and management of green and blue spaces (Shaamala et al., 2024). Other works showed that AI-driven models coupled with publicly available satellite data can improve urban planning, resource allocation, and green blue space conservation (Hasan et al., In press). AI and multimodal datasets have the potential to help create holistic and adaptable systems that integrate green and blue infrastructure to address interconnected climate-related challenges

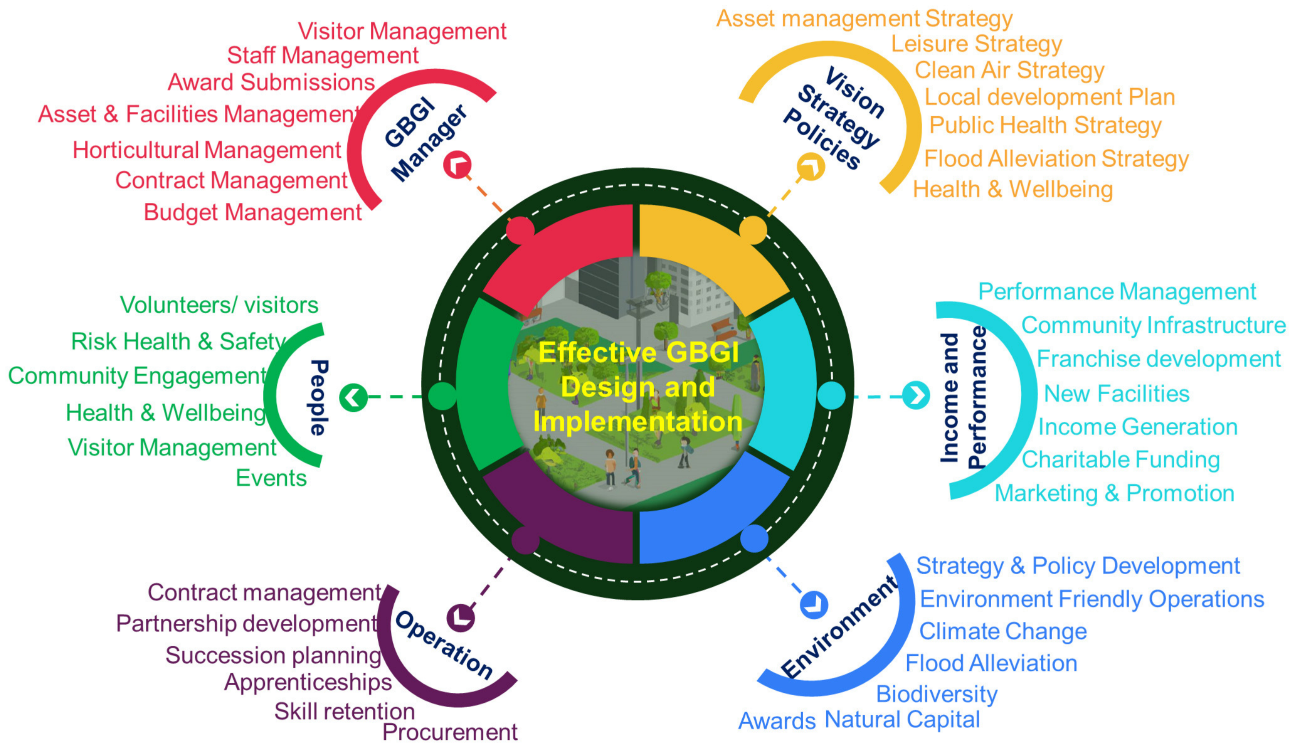

FIGURE 2
Dimensions for effective GBGI design and implementation. This diagram illustrates the interconnected dimensions for a successful GBGI project, including GBGI manager, people, operation, environment, income and performances and vision, strategy and policies. Adapted from APSE (2019).

such as flood control, biodiversity enhancement, and urban cooling (Islam M. R. et al., 2024).

The UK Met Office, for example, is committed to improving climate projections and ensuring their practical use for organizations and individuals (Met Office, 2025b). Additionally, organizations like UKRI are funding projects that generate large-scale environmental data, such as mapping the heat registry of every house in the UK to identify areas needing intervention. Ensuring that all funded research is open-source allows stakeholders, authorities and researchers to access valuable data and target interventions or research gaps. However, a major challenge lies in managing the volume of data and making it easily accessible. Addressing this requires investment in large-scale data infrastructure and smart interface solutions.

4.8 Long-term management strategies

Adaptive management strategies are essential for sustaining urban greening efforts in the long run, along with monitoring and evaluation. Regular environmental assessments using remote sensing technologies, satellite imagery, and GIS mapping can help monitor the health and effectiveness of green spaces and ecosystems. These tools enable urban planners to identify areas in need of intervention, track biodiversity trends, and assess the cooling impact of different greening solutions. Integrating urban greening with climate adaptation policies, such as flood mitigation through green infrastructure, drought-resistant landscaping, and urban heat island reduction strategies, enhances the resilience of cities against climate risks. Moreover, maintaining green spaces requires sustainable funding and governance structures. Many urban greening initiatives face long-term financial challenges, particularly when initial investments are not accompanied by maintenance plans (Pearsall et al., 2024). Innovative financing mechanisms, such as green bonds, corporate social responsibility (CSR) contributions, and public–private partnerships, can help secure ongoing funding.

5 Conclusion and future outlook

Urban areas have undergone a transformation from walkable, compact spaces to car-dominated sprawl. In recent years, there has been an increased focus on the development of sustainable and environmentally-friendly urban areas. This transition highlights the complex interplay of technological, social, and environmental factors that influence such developments. As urbanization accelerates, the demand for sustainable urban development has increased significantly. This urgency is further emphasized by global initiatives, such as the Sustainable Development Goals (SDGs), especially SDG11, which focuses on Sustainable Cities and Communities. Additionally, other SDGs, such as SDG 3, 7, 8, 9, 12, and 13 underline the importance of creating resilient and sustainable urban environments.

Urban greening is not just an aesthetic enhancement but a fundamental component of sustainable urban development.

Integrating GBGI into new and existing urban areas can help tackle environmental challenges while creating healthier, more livable spaces. With strategic planning, investment, and community engagement, urban greening can transform cities into climate-resilient, vibrant, and inclusive places for present and future generations, addressing the issues of extreme heat, air pollution, and loss of biodiversity. However, effective implementation of GBGI requires a multidisciplinary approach that aligns policy support, financial mechanisms, community engagement, and technological advancements. By addressing key challenges and leveraging collaborative governance, innovative funding, and data-driven decision-making, cities can successfully scale up GBGI, shifting from gray infrastructure dominance to climate-resilient inclusive urban landscapes.

Looking forward, urban greening will increasingly be shaped by technological advancements, innovative financing mechanisms, and a stronger emphasis on community participation and social equity. By embracing cutting-edge strategies and fostering multi-sectoral collaboration, future urban areas can strike a balance between development and sustainability, ensuring a greener, healthier, and more resilient world for future generations. Effective urban greening requires a comprehensive strategy that includes policy support, innovative financing, technological advancements, interdisciplinary collaboration, and community participation. Additionally, by addressing financial barriers, streamlining governance, utilizing data-driven decision-making, and fostering public engagement, cities can successfully implement urban greening initiatives. To ensure inclusive climate-resilient urban greening, urban areas must prevent green gentrification, prioritizing underprivileged communities, adopting adaptive management strategies, and securing long-term funding. As urban populations continue to grow and climate change intensifies, inclusive urban greening with careful and strategic planning is not just an option but a necessity for building just and sustainable cities.

Author contributions

PK: Project administration, Writing – original draft, Supervision, Investigation, Writing – review & editing, Conceptualization, Methodology, Funding acquisition. JS: Investigation, Methodology, Writing – review & editing, Data curation. KC: Data curation, Writing – review & editing, Methodology, Investigation, Visualization. AA: Methodology, Writing – review & editing, Resources, Validation. MFA: Validation, Writing – review & editing, Methodology. MA: Investigation, Validation, Writing – review & editing, Methodology. S-JC: Writing – review & editing, Validation, Investigation, Methodology. LC: Investigation, Writing – review & editing, Resources, Conceptualization. SDe: Validation, Writing – review & editing, Investigation, Methodology. SDi: Writing – review & editing, Validation, Conceptualization. CHH: Conceptualization, Validation, Writing – review & editing. FH: Conceptualization, Validation, Writing – review & editing. CH: Writing – review & editing, Conceptualization, Validation. LI: Writing – review & editing, Conceptualization, Validation. LJ: Funding acquisition, Validation, Conceptualization, Writing – review & editing. TR: Conceptualization, Validation, Funding acquisition, Writing – review & editing. BM: Conceptualization, Writing – review & editing, Validation. AM: Conceptualization, Writing – review & editing, Validation. RK: Conceptualization, Validation, Writing – review & editing. SK: Conceptualization, Validation, Writing – review & editing. ES: Writing – review & editing, Validation, Conceptualization. GO: Validation, Writing – review & editing, Conceptualization. KR: Conceptualization, Writing – review & editing, Validation. NR: Investigation, Writing – review & editing, Validation. VS: Conceptualization, Validation, Writing – review & editing. JW: Writing – original draft, Writing – review & editing, Validation. HW: Validation, Conceptualization, Writing – review & editing. RY: Conceptualization, Writing – review & editing, Validation.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work is conducted as part of the United Kingdom Research & Innovation (UKRI)-funded RECLAIM Network Plus (EP/W034034/1; EP/W033984/1). The network is jointly funded by three UKRI research councils: the Engineering and Physical Sciences Research Council (EPSRC), the Natural Environment Research Council (NERC), and the Arts and Humanities Research Council (AHRC). PK and co-leads acknowledge the support received through the UKRI funded GP4Streets (APP44894), DEFRAG (NE/W002892/1), GREENIN (APP55977), NERC-FAPESP funded GreenCities (NE/X002799/1; NE/X002772/1; FAPESP Grant No. 2022/02365-5), and the University Global Partnership Network (UGPN)-funded UGPN-NBS projects.

Acknowledgments

The authors gratefully acknowledge the contributions of all RECLAIM Conference panel members, attendees, co-leads, coordinating staff, event organizers, speakers, and collaborating partners. We also extend our appreciation to the University of Surrey's Global Centre for Clean Air Research (GCARE) team for their invaluable support in running both the conference and network operations. The names of co-authors are listed in alphabetical order following the core writing team.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

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