Building Urban Resilience Through Nature: A Systematic Review of Urban Green Spaces as Nature-based Solutions

Abstract

Nature-based Urban Green Spaces (NBUGS) are increasingly recognized as essential strategies for enhancing urban resilience and addressing interconnected environmental, social, and economic challenges. Despite growing implementation, comprehensive evidence synthesis examining their multidimensional impacts and evaluation frameworks remains limited. This systematic review synthesizes evidence from 128 peer-reviewed empirical studies on NBUGS. Our analysis reveals exponential growth in NBUGS research, geographically concentrated in economically developed countries and regions. The evidence confirms that urban resilience is significantly enhanced by environmental benefits, positive social and economic outcomes. However, current research exhibits notable limitations including fragmented evaluation frameworks, lack of standardized resilience metrics, and insufficient integration of smart monitoring technologies. Realizing the full potential of NBUGS for urban resilience requires fundamental shifts toward standardized evaluation frameworks, dynamic management systems, and integrated planning approaches that explicitly address equity concerns and long-term sustainability. Future research priorities include developing modular assessment protocols, designing real-time resilience monitoring systems, establishing data-sharing platforms, and investigating synergies and trade-offs across benefit dimensions.

Keywords: Nature-based solutions; Urban green spaces; Urban resilience; Ecosystem services; Climate adaptation; Resilience monitoring

1. Introduction

Global urbanization continues to advance at an unprecedented speed and scale, this rapid urban expansion exerts immense pressure on the natural environment (Li et al., 2024). The process of urbanization brings development opportunities but is also accompanied by a series of severe environmental, social, economic and healthy challenges (Chàfer et al., 2020; Ramon et al., 2023; Thapa et al., 2024). The interconnectedness and urgency of various urban challenges mean that singular, problem-specific solutions often fail to achieve desired outcomes (Li et al., 2025; Moreno et al., 2024). This complexity calls for integrated strategies that can address multiple urban challenges simultaneously while ensuring social equity and inclusiveness. Nature-based Solutions (NBS) represent precisely such an approach, gaining widespread attention as an innovative and sustainable strategy for urban development. According to the International Union for Conservation of Nature (IUCN), NBS address societal challenges through actions to protect, sustainably manage, and restore natural and modified ecosystems, benefiting people and nature at the same time. It transforms natural ecosystems from passive objects of protection into active participants in addressing complex environmental, social and economic challenges, making NBS an effective strategy to solving urban problems.

In highly human-modified cities, Urban Green Spaces (UGS) are core elements for implementing NBS. The World Health Organization (WHO, 2017) defines UGS as "all urban land covered by vegetation of any kind." UGS take many forms, including parks, gardens, tree-lined avenues, green roofs, vertical greening, urban forests, constructed wetlands, and green belts forming urban ecological network. UGS can provide ecological, social, and even economic benefits simultaneously within the same green space (Liu et al., 2023). Moreover, achieving synergistic solutions to multiple urban problems through the input of a single natural system is a concentrated embodiment of the core value of UGS as NBS. In this review, Nature-based Urban Green Spaces (NBUGS) are defined to represent the UGS that are intentionally planned, implemented, or maintained under ecological principles to address environmental, social, and economic urban challenges through the ecosystem services they provide.

Although the potential of NBUGS in addressing urban challenges has been widely recognized in both academia and practice, existing research still exhibits notable deficiencies and limitations in several aspects. Firstly, against the backdrop of rapid urbanization, there is insufficient research of the development trends of NBUGS in research and practice over the past decade, preventing researchers from quickly and accurately exploring the current research status. Secondly, the quantitative evaluation system for the integrated benefits of NBUGS remain imperfect due to scarcity of comprehensive evaluation frameworks and empirical analyses for diverse effects. Much of the existing research tends to focus on a specific benefit, such as ecological or social benefit, failing to systematically examine the synergistic relationships, potential trade-offs, and overall cost-effectiveness (Raymond et al., 2017) Additionally, evaluation methods and indicators for NBUGS implementation effects lack standardization, limiting the comparability of research and the generalizability of experiences (de la

Barrera et al., 2023). Lastly, with the frequent emergence of new problems and challenges in urban development, there is a dearth of forward-looking articles on future research directions, which inhibits the widespread promotion and development of NBUGS.

To address the limitations, this research adopts a systematic review to identify the strength and deficiencies of evidence and summarize successful implementation experiences and common challenges across contexts.

The purposes of this systematic review are explicitly defined as follows:

(1) To explore the development trends in research and practice of NBUGS over the past decade, including dynamic changes in the number of related publications and the practical implementation of NBUGS in cities worldwide.

(2) To summarize the multidimensional impacts generated by NBUGS, to catalogue the main ecosystem services and socioeconomic benefits they provide, and to synthesize research from various fields to obtain a holistic understanding.

(3) To investigate and evaluate the tools and methods for evaluating the benefits of NBUGS, comparing the application of methods and participatory evaluation across different dimensions, and analysing their respective advantages and limitations.

(4) To identify existing deficiencies and gaps in current research, and to propose future research directions and practical improvement suggestions.

The remainder of this study is structured as follows: Section 2 elaborates on the literature screening methods and data extraction process; Section 3 presents the literature research results, systematically reviewing the research trends and distribution of NBUGS; Section 4 summarizes the environmental, social, and economic impacts of NBUGS; Section 5 summarizes the tools and frameworks used in different NBUGS implementation phases; Section 6 compares and summarizes the indicator systems and evaluation models adopted in existing research; Section 7 discusses these results and propose issues and directions for future research; Section 8 then concludes the entire paper.

2. Methodology

This study adopts a systematic review approach following PRISMA guidelines to systematically identify, screen, and synthesize empirical evidence on NBUGS. The research methodology comprises four main phases: (1) systematic literature search across major academic databases, (2) screening and selection based on predefined inclusion/exclusion criteria, (3) data extraction and coding of selected studies, and (4) qualitative synthesis and thematic analysis of findings. This approach ensures transparency, reproducibility, and comprehensive coverage of the existing evidence base.

2.1 Literature Search Strategy

In this study, a systematic search of two major academic databases, Scopus and Web of Science (WoS), was conducted in Apr. 2025 to capture relevant literature in past decade. The search strategy combined terms for nature-based solutions and urban green infrastructure. The applicated Boolean logic is shown in Table1. Initial research was refined iteratively to balance sensitivity and precision. To ensure the research quality and accuracy, only the peer-reviewed journal articles in English, published 2016–2025 were included. Additional records were identified by screening reference lists of key review papers and via expert knowledge, to ensure inclusion of influential publications not indexed or captured by the initial queries.

Table 1: Boolean logic key words for paper searching

Level 1	“nature based solution*”OR “NBUGS” OR “nature-based solution*”
Level 2	(stakeholder* OR human OR participant* OR engagement OR perception OR governance OR policy)
	(price* OR economy OR investment OR innovation OR development) OR (“heat wave” OR carbon OR temperature OR climate OR ecosystem OR microclimate)
	(mental OR health OR “well-being” OR age)
Level 3 Main Keywords: Green Space	"green space" OR park OR "open space" OR "public space" OR "landscape" OR “vertical green*” OR "green belt" OR "green way" OR "garden" OR "green infrastructure"

2.2 Selection Criteria

This study employs Zotero reference management software to import and manage all retrieved literature data, removing duplicates before conducting an initial screening of the documents. A rapid screening of titles and abstracts was performed first to exclude obviously irrelevant literature.

The exclusion criteria for the literature included:

(1) Language and accessibility: Non-English written literature or full papers unavailable

(2) Publication type: Non-peer-reviewed studies, non-original articles (e.g., conference papers, literature reviews, editorials, commentaries), or publications outside the timeframe of 2016-2025

(3) Topic relevance: Studies not related to urban green spaces, green infrastructures, or Nature-Based Solutions

(4) Methodological rigor: Studies without specific benefit assessments, data analysis, or empirical research

2.3 Study Selection Process

The study selection process is summarized in a PRISMA flow diagram (Figure 1). This diagram documents the number of records identified, screened, and included at each stage. The initial database search yielded 2444 records, and the latest data collection was performed in April 2025. After removing 961 duplicates, 1483 unique records remained. Title and abstract screening exclude 1163 non-relevant papers, with 320 articles progressing to full-text review. Of these, 213 papers were excluded resulting in 107 studies included in qualitative synthesis and quantitative analysis. Additionally, the review adds 21 articles to the database through a snowball screening, making the final database size 128 documents.

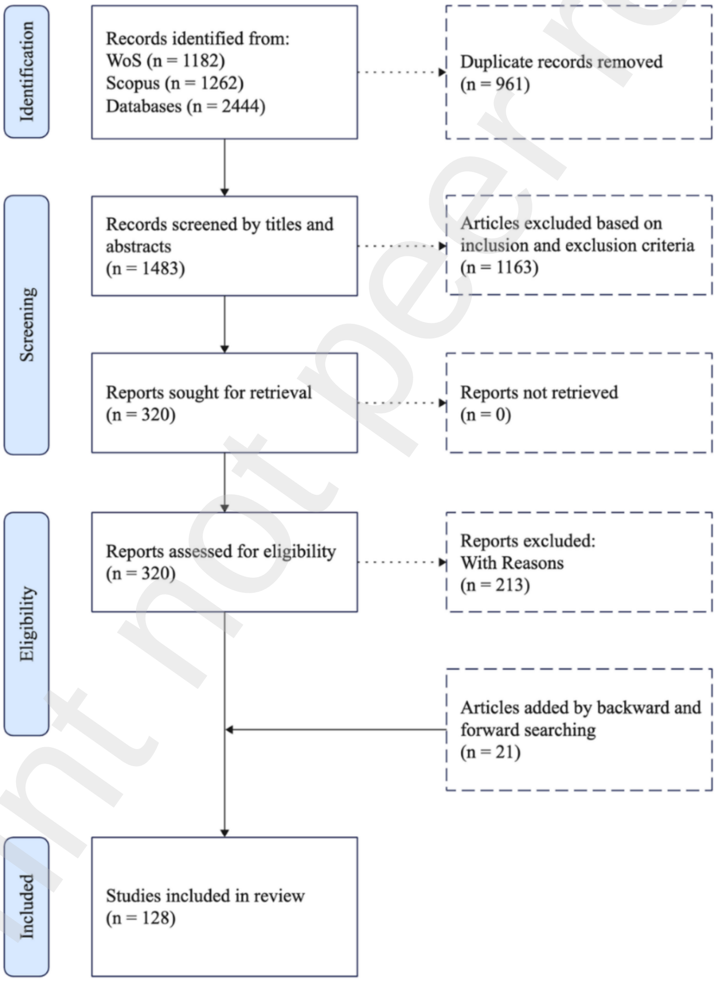

Figure 1. Literature selection process based on PRISMA flow diagram

3. Publication Trends and Global Distribution

Over the past decade, NBUGS has transitioned from an emerging concept to a mainstream topic in environmental research. Figure 2 illustrates that starting from 2016, only a small number of studies on NBUGS were published annually. Since 2020, this number has grown exponentially, reflecting a global increase in academic interest in NBUGS centred environmental research and the recognition of NBUGS as a key component of urban sustainability science. In 2020, the EU Horizon 2020 program announced its research and innovation agenda, and in the same year, the IUCN released the NBS Global Standard. The growth trend in literature partly reflects the impetus of these milestone policies provided to the academic community.

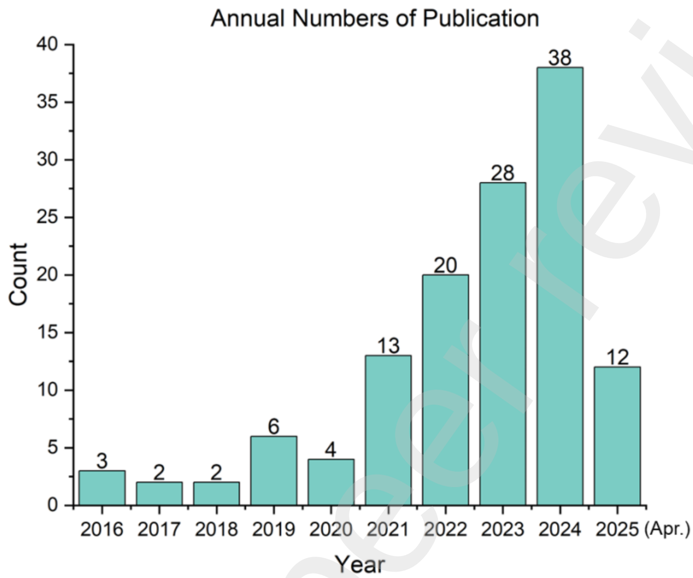

Figure 2. The change in annual numbers of publication from 2016 to 2025(Apr.)

Geographically, research and implementation of NBUGS were widespread globally, but the distribution of research areas is uneven. Figure 3 shows that Europe is an active region for NBUGS academic research. Countries such as Italy, Germany, Finland, and the United Kingdom are leaders in NBUGS projects and academic output, and these studies have often been supported by EU research programs (Kato-Huerta & Geneletti, 2022).

The North America is a significant contributor, with the United States and Canada conducting substantial research on the application of green infrastructure in flood management and urban heat island mitigation. In recent years, research in Asia has been rapidly increasing, primarily concentrated in economically developed countries and regions such as China, Singapore, and South Korea. Research in China is mainly focused on economically developed eastern coastal areas like Shanghai, Beijing, Nanjing, and Guangzhou. However, western and northern cities facing greater climate vulnerability remain under-researched. The volume of relevant research literature from Australia has also grown considerably in recent years, establishing a certain influence in the field of NBUGS-related research. Although research publications are increasing in Latin American countries such as Brazil and Mexico, in African countries like Egypt and in South Asian countries such as India, and Vietnam, the overall output from the Global South remains limited.

Overall, NBUGS represents a global research wave, with more countries and regions focusing on global sustainability research centred on this concept. Nevertheless, resource-scarce and climate-vulnerable developing regions still require more research support.

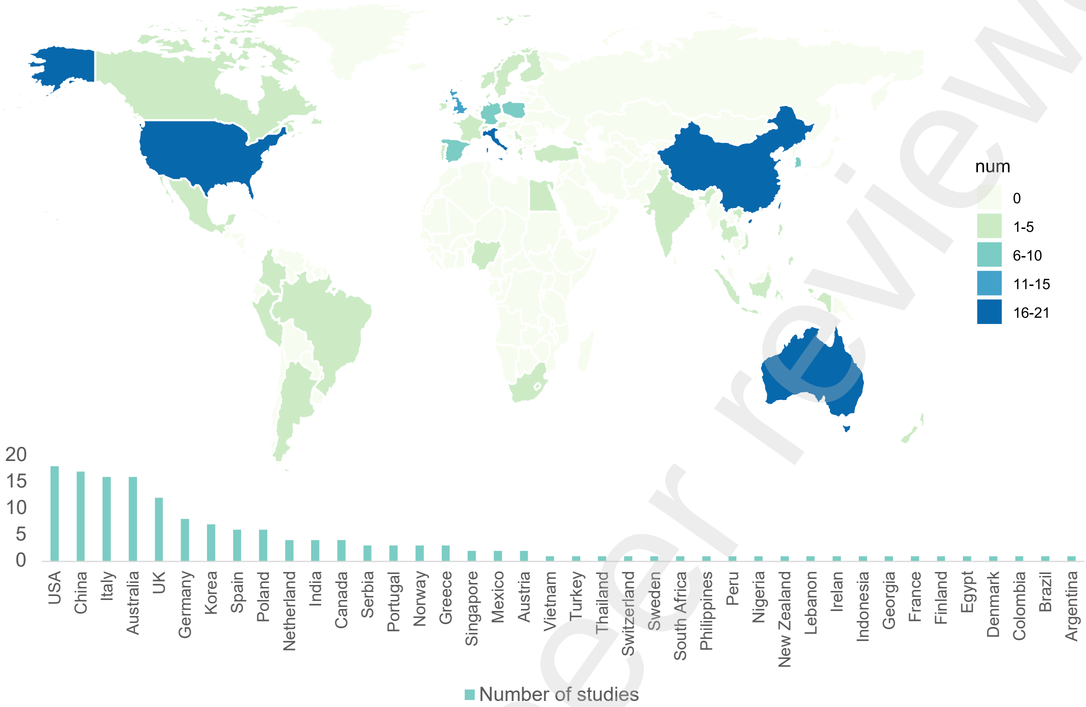

Figure 3. Geographical distribution of NBUGS research countries (based on the case study location).

4. Multidimensional Impacts of NBUGS

One of the key motivations for incorporating NBUGS into city building and planning is its potential to deliver environmental, social, and economic benefits, promoting healthy, prosperous, and sustainable urban development. NBUGS can improve urban environmental quality, enhance well-being, and contribute to economic value, although benefits vary with geographical environments and implementation schemes (Liu et al., 2023; Mao et al., 2023; Xu & Zhao, 2023). Furthermore, consideration should be given to trade-offs in NBUGS implementation and a possible unexpected negative influence. This section analyses and summarizes NBUGS impacts on urban development from environmental, social, and economic perspectives.

4.1 Environmental Benefits and Ecosystem Services

Most research affirms that NBUGS improves the urban environment, mitigates climate change impacts, and promotes urban sustainability. Approximately 60% of the articles focus on environmental conditions. They provide key ecosystem services, including regulating urban microclimates (Chàfer et al., 2020; Cui et al., 2023; N. Zhang et al., 2024), managing hydrological processes (Espinal-Giron et al., 2023; Greksa et al., 2023; Twohig et al., 2022), improving air quality (Fornaciari et al., 2024; Moreno et al., 2024;

Ramon et al., 2023) and enhancing biodiversity (Aronson et al., 2017; Xie & Bulkeley, 2020).

4.1.1 Urban Climate Regulation

A primary benefit of NBUGS is urban climate regulation and mitigation of the urban heat island effect. Vegetated areas regulate high temperatures through shading and evapotranspiration, counteracting the urban heat island effect (Alpaidze & Pace, 2021; Anderson & Gough, 2022; Anjum et al., 2024; Berglihn & Gómez-Baggethun, 2021; Matter & Gado, 2024). For example, NBUGS such as urban parks, green corridor networks, and urban forests have been shown to reduce land surface temperature (LST) by an average of 0.5°C - 5°C compared to surrounding built-up areas (Chàfer et al., 2020; Guo et al., 2024; Marando et al., 2019; Pritipadmaja et al., 2023; Veerkamp et al., 2024). Liang et al. (2023) found that the cooling effect of parks varies seasonally, averaging 1.28°C in summer and only 0.3°C in winter. Xu et al. (2022) found that increasing NBUGS quantity reduces average urban LST, while more equitable NBUGS distribution can decrease LST clustering and improve urban thermal environment.

4.1.2 Hydrological Regulation

Another major service of NBUGS is reducing the negative impacts of disasters such as floods and storms on cities. Greksa et al. (2023) demonstrated that rain gardens can reduce water flow during storms and decrease the presence of standing water or overflow. Furthermore, green roofs and infiltration trenches also help increase urban permeability and water storage capacity. NBUGS can reduce peak runoff and the burden on sewer systems, while providing safe buffer zones for urban residents during extreme weather events (Espinal-Giron et al., 2023; Gupta & Dixit, 2024; Ncube & Arthur, 2021). In coastal Naples, NBUGS is found to reduce economic losses caused by coastal flooding (Clemente et al., 2023). Staccione et al. (2024) found that expanding the urban green network by 25% could potentially halve flood losses and reduce the exposed population by 40%. Across all analysed rainfall intensities, increasing green space coverage reduced building damage by up to 60% and the exposed population by approximately 50%.

4.1.3 Air Quality Improvement

Trees in urban forests and parks are a straightforward reflection of the NBUGS concept. These trees serve as natural barriers, effectively capturing various particulate matter (PM) and purifying air pollutants such as nitrogen and sulphur compounds. This can reduce air pollution and improve human health and well-being(Fornaciari et al., 2024; Moreno et al., 2024; Ramon et al., 2023). Chen et al. (2016) studied the effect of NBUGS on reducing PM2.5 concentrations, finding that trees were effective in reducing PM2.5 in spring but had limited impact in other seasons. The researchers further indicated that the importance of green vegetation across all reasons, given the spatiotemporal complexity influenced by factors such as meteorological conditions and human activities. Anderson et al. (2023) used satellite remote sensing to demonstrate that trees and dense vegetation around industrial areas can effectively reduce nitrogen dioxide and improve air quality.

4.1.4 Biodiversity Enhancement

NBUGS can also enhance urban biodiversity. Restoring green habitats in cities can provide more environments for native animals to survive and offer habitats for wildlife, increasing species richness in urban areas (Aronson et al., 2017). In some instances, species richness in cities could even approach the biodiversity levels of natural reference sites (Li et al., 2025). The enhancement of biodiversity is not limited to large-scale NBUGS interventions such as urban forests, urban parks, and constructed wetlands, but is also reflected in smaller-scale interventions. Wooster et al. (2022) found that green roofs support up to four times more bird species, over seven times more arthropods, and twice the gastropod diversity compared to traditional roofs, indicating that small-scale green infrastructure promotes species diversity.

4.2 Social Benefits and Community Well-being

NBUGS also has significant impacts on the social level. Numerous studies indicate that NBUGS can alleviate residents' anxiety and depression, and improve their health conditions (Anderson et al., 2021; Cao et al., 2023; Quan et al., 2024; Shen, 2025; Thapa et al., 2024). NBUGS has also been found to enhance community cohesion and residents' sense of pride and identity (Cardinali et al., 2024; Truong et al., 2022). Furthermore, NBUGS are supported to reduce crime and suicide rates (Navarrete-Hernandez & Afarin, 2023). However, despite the positive effects of NBUGS in improving social well-being, when considered from a multidimensional perspective, NBUGS can also pose challenges to community equity and justice (Anguelovski et al., 2018; Kato-Huerta & Geneletti, 2022; Li et al., 2025).

4.2.1 Human Well-being and Health

Over the past decade, researchers have linked NBUGS to a range of positive health effects. NBUGS such as urban gardens, urban parks, urban forests, and community green spaces are significant for residents' mental health (Rastkhadiv et al., 2024; Syamili et al., 2023; J. Zhang et al., 2024). Vujcic et al. (2017) confirmed that living in communities with more green spaces can effectively reduce emotional instability, such as depression and anxiety, in psychiatric patients. Stenfors et al. (2024) found that residential greenspace is associated with statistically significantly lower prevalent and incident antidepressant medication redemptions. This correlation is especially strong for green spaces within the nearest residential buffer zone. Specially, some studies show that under sunny conditions, the restorative and promotional effects of NBUGS on people's physical and mental well-being are stronger (Bandurski et al., 2020; Cao et al., 2023). Beyond direct effects on well-being, Beele et al. (2024) indicated that green spaces can mitigate heat-related stress and enhance sleep quality, thereby improving overall well-being during heat events. NBUGS also offers health benefits to vulnerable groups such as children and the elderly by mitigating heat-related health risks (Andreucci et al., 2019; Davis et al., 2025). Beyond residential areas, green environments positively impact hotel guests and employees, enhancing guests' living experience and reduce employees' stress and anxiety (Han et al., 2020; Yu et al., 2020).

4.2.2 Community Cohesion and Safety

From a community perspective, NBUGS offers additional social benefits that provide impetus for urban development. These green spaces can foster connections among residents, thereby enhancing social cohesion and community resilience. When residents gather in parks, gardens, or green courtyards, they have opportunities for positive interactions, recreation, and collective activities, which help build trust and social connections (Camps-Calvet et al., 2016; Oh et al., 2022; Twohig-Bennett & Jones, 2018). Research also indicates that community gardens are not only important venues for promoting human-nature connections but also help enhance community awareness and improve residents' positive perceptions of public housing (Lanier et al., 2015; Truong et al., 2022). Furthermore, for low-income populations and vulnerable groups, participating in community garden activities is an effective way to increase community pride and strengthen community cohesion (Cardinali et al., 2024).

Some studies suggest that NBUGS has the potential to reduce violent crime and effectively improve community safety (Navarrete-Hernandez & Afarin, 2023; Zhang et al., 2025). Ryan et al. (2023) found that increased neighbourhood greenspace accessibility and tree canopy cover were associated with reduced intentional deaths, with park accessibility demonstrating a particularly significant impact. They also pointed out that future policy and research should focus on improving equitable access to existing and future greenspaces, especially in primarily disadvantages neighbourhoods. Therefore, expanding and promoting NBUGS has become a key policy measure for enhancing safety (Navarrete-Hernandez & Afarin, 2023).

4.3 Economic Performance and Cost-Effectiveness

NBUGS also affect urban economic development, providing direct cost-benefit aspects and indirect benefits from ecosystem services (Koppelaar et al., 2021; Vicarelli et al., 2024).

NBUGS represents a cost-effective solution, often leading to cost savings in various situations (Clemente et al., 2023). Vicarelli et al. (2024) found that in over 71% of cases, nature-based interventions are more cost-effective than engineered alternatives. NBUGS can also control operation and maintenance phase costs through their inherent ecosystem service systems. Green roofs in cities have a positive impact on various aspects of the urban environment and building energy efficiency (Mesimäki et al., 2019; Pumo, Alongi, et al., 2023). The implementation of green roofs, have positive effects on diverse aspects of urban environments and building energy savings, which are particularly evident in both summer and winter. (Savić et al., 2024). Furthermore, rain gardens and green roofs can significantly reduce hydrological disasters caused by floods and storms in cities, thereby reducing economic losses due to extreme weather events (Clemente et al., 2023; Staccione et al., 2024). It is worth noting that some economic benefits brought by NBUGS are dispersed and long-term, which make them difficult to detect and quantify. For example, the long-term benefits of carbon sequestration from urban forests and the reduction of overall urban energy consumption through mitigation of the urban heat island effect (Babí Almenar et al., 2023; Fornaciari et al., 2024; Guo et al., 2024).

In addition to direct cost-effectiveness, NBUGS also create economic value by increasing real estate value and commercial attractiveness (Fernandez, 2023; Gałecka-Drozda et al., 2021). Setiowati et al. (2024) demonstrated that parks and urban forests increase land prices by 9.2%, 17.1%, and 19.2% within 0.5-2 km impact zones, while Brisbane's Victoria Park generated 3% property price increases within 750 meters (Bottero et al., 2022). Relevant research indicates that proximity to urban parks, greenways, or waterfront restorations increase property prices or rental premiums because these amenities are capitalized into housing market (Ao et al., n.d.; Wolch et al., 2014). Green spaces surrounding retail establishments such as supermarkets and shopping malls attract more customers and increase foot traffic, which in turn enhances sales revenue and contributes to local economic development (Koppelaar et al., 2021). Similarly green spaces within hotels enhance customer satisfaction and increase repeat stays, improving hotel sales performance (Yu et al., 2020). NBUGS can also create green job opportunities such as landscaping, maintenance and horticulture, while stimulating eco-tourism and recreation-related expenditures (Raymond et al., 2017).

4.4 Equity and Justice Consideration

Although NBUGS demonstrates positive benefits at ecological, social and economic levels, their impacts are diverse and must be viewed from a multidimensional perspective. From an equity and environmental justice perspective, research reveals that many NBUGS projects lack explicit consideration of equity, resulting in uneven distribution of access to high-quality green spaces (Kato-Huerta & Geneletti, 2022; Li et al., 2025; Wolch et al., 2014). Typically, affluent communities have more and better-maintained parks and tree coverage, while marginalized communities have sparse and poor-quality green spaces. This imbalance further exacerbates public health inequalities. Populations with the greatest health needs and who would benefit most from ecosystem services often have the least access to quality green spaces. (Kato-Huerta & Geneletti, 2022). Without systematic planning, well-intentioned greening initiatives may inadvertently exacerbate social inequalities, with green gentrification emerging as a significant adverse consequence. Anguelovski et al. (2018) analysed 28 cities across 9 countries, finding that greening interventions during the 1990s–2000s correlated with gentrification in 17 cities over the subsequent decade. The mechanism involves green spaces elevating housing costs, which displaces economically disadvantaged residents and reconstitutes of neighbourhood demographics toward higher-income populations (Bottero et al., 2022; Cole et al., 2019; Jamalishahni et al., 2023; Rigolon et al., 2021).

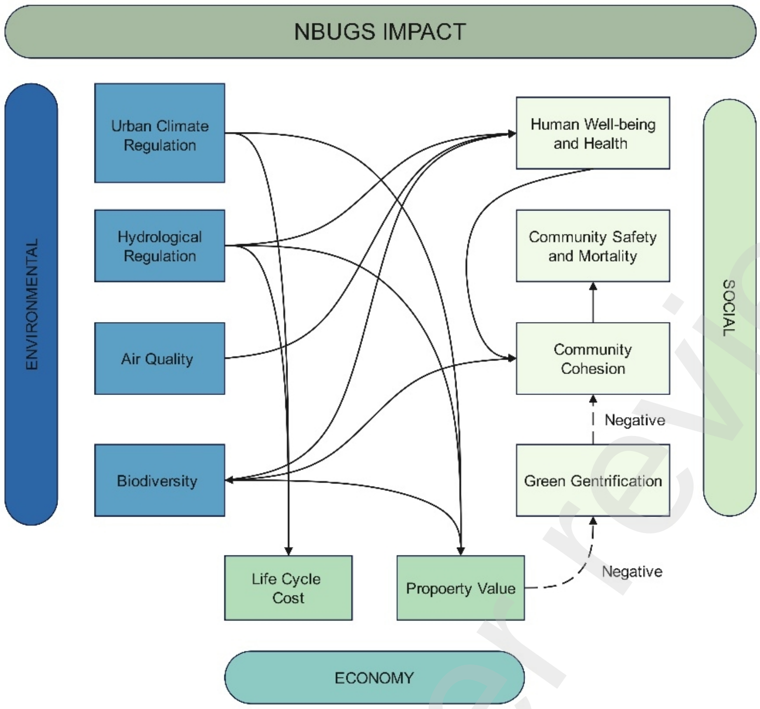

Figure 4 The relationship between different aspects of NBUGS Impact

Figure 4 shows that NBUGS generates complex cascading effects across environmental, social, and economic dimensions, creating both synergistic benefits and potential trade-offs through interconnected pathways. This emphasizes that NBUGS effectiveness depends critically on understanding and managing these multidimensional interactions rather than optimizing single benefits in isolation. Successful implementation requires anticipating potential unintended consequences and establishing safeguards to prevent adverse outcomes. Given that NBUGS interventions produce multiple interconnected effects across environmental and social domains. Planners must adopt integrated approaches that enhance positive synergies while mitigating negative impacts through equitable design and meaningful community engagement (Bottero et al., 2022; Raymond et al., 2017; J. Zhang et al., 2025).

5. Implementation

Effective implementation of NBUGS requires careful integration of technical tools, spatial strategies, and social considerations. This section examines how planners and practitioners navigate the complex implementation process of NBUGS, drawing on recent advances in spatial analysis, simulation technologies, and stakeholder engagement.

5.1 Pre-Implementation Analysis and Decision-Making

NBUGS implementation has evolved from isolated project-based interventions to systematic, evidence-based planning approaches. This transformation relies heavily on the synergistic use of geospatial technologies and multi-criteria frameworks.

Geographic Information Systems (GIS) and Remote Sensing (RS) have become indispensable in this process, enabling practitioners to monitor urban green space dynamics, assess site suitability, and optimize ecological corridor networks (Azadgar et al., 2025; Battisti et al., 2024; Gupta & Dixit, 2024). These technologies and methods adopt a macro-level perspective to identify priority implementation areas and evaluate service coverage, analysing and adjusting the layout of NBUGS to maximize its overall benefits, particularly for heat mitigation and flood risk reduction (Langemeyer et al., 2020; J. Wang et al., 2023; C. Xu et al., 2022).

While spatial analysis provides crucial insights, the pre-implementation decision-making process further requires evaluating and comparing alternative NBUGS designs or sites based on multiple criteria. Multi-Criteria Decision Analysis (MCDA) provides a systematic framework for such evaluations, incorporating stakeholder preferences and resource constraints into the selection process (Ahmed et al., 2024; Ahmed & Loc, 2023; Rastkhadiv et al., 2024). Recent applications demonstrate the practical value of integrating spatial analysis with decision frameworks. Z. Xu & Zhao (2023) employed multi-scale GIS and RS analysis to quantify cooling efficiency across Beijing, revealing that NBUGS achieved optimal performance at the 300-meter scale. Similarly, Battisti et al. (2024) combined spatial mapping with MCDA to prioritize urban forest implementation sites in Turin, Italy. This integrated approach allowed them to balance ecological benefits with social accessibility, demonstrating how spatial tools can inform strategic decision-making when coupled with structured evaluation methods. This method proves particularly valuable when prioritizing interventions across cities or determining optimal green infrastructure configurations under budget limitations (Croeser et al., 2021).

Beyond spatial optimization, practitioners increasingly rely on simulation tools to predict NBUGS performance before implementation. ENVI-met has gained highlight for its ability to provide high-resolution dynamic simulation of multi-dimensional microclimate environments (Mukherjee, 2024). It has been widely used to simulate and model microclimate interactions between vegetation, water features, and built environments. This allows researchers evaluating thermal comfort improvements and air quality benefits across different NBUGS configurations (Kaçmaz Akkurt & Şemsiyeci, 2024; Su et al., 2022; Torkfar & Russo, 2023). For hydrological performance, the Storm Water Management Model (SWMM) enables detailed assessment of how rain gardens, green roofs, and other NBUGS reduce runoff volumes and peak flows during storm events (Alemaw et al., 2020; El Baida et al., 2024; Sciuto et al., 2024).

Environmental impact assessment tools provide another layer of decision support. Life Cycle Assessment (LCA) helps researchers evaluate the full environmental footprint of NBUGS compared to conventional grey infrastructure, identifying critical stages where interventions can reduce negative impacts (Larrey-Lassalle et al., 2022). Carbon and water footprint analyses complement these assessments by quantifying specific resource implications throughout project lifecycles. It can also guide scientific optimization and decision-making for urban green space construction, ecological restoration, and water resource management measures (M. Wang et al., 2024).

5.2 Implementation Strategies and Technical Approaches

The translation from planning to implementation of NBUGS follows diversified methodologies based on specific objectives, site conditions, and available resources. These methods and strategies often integrate various technical capabilities with local conditions and stakeholders needs to achieve effective implementation from macro-level planning to micro-level design.

Spatially driven implementation emphasizes macro-level green space configuration to maximize citywide benefits. This approach prioritizes systematic identification of intervention areas through comprehensive spatial analysis. Liu et al. (2023) and Wang et al. (2023) demonstrated how multi-source data integration can reveal gaps in green space distribution and guide strategic placement of new NBUGS. The strength of this approach lies in its ability to address inequities in ecosystem service provision across urban areas, though it requires substantial data infrastructure and inter-departmental coordination (Azadgar et al., 2025).

Site-specific implementation strategies focus on technical optimization of individual NBUGS projects. These strategies often concentrate on the development, construction and renovation of specific types of green infrastructure, such as rain gardens, green roofs, urban forests, etc. Their characteristics include verifying the feasibility and benefits of NBUGS measures at the project scale, indicating the application of innovative materials, structures, and configurations to enhance performance (Boros & Mahmoud, 2021; Pumo, Francipane, et al., 2023). Torkfar & Russo (2023) applied iterative simulation-design cycles in a Cheltenham parking lot renovation, achieving radiant temperature reductions of 6-15°C during extreme heat events. This methodology is a structured, evidence-based framework that enables a design-simulation-redesign cycle, allowing NBS concepts to be iteratively tested and refined through numerical modelling to achieve optimal implementation outcomes.

The choice between extensive spatial planning and intensive site development often reflects resource availability and project scale. However, some practices suggest these strategies are most effective when combined. Kasprzyk et al. (2022) illustrated this integration in their Gdańsk rain garden implementation. They developed citywide hydrological mapping to identify priority areas, then tailored site-specific technical design adapted solutions to local soil conditions and drainage patterns. This multi-scale approach acknowledges that successful NBUGS implementation requires both strategic vision and technical precision.

5.3 Social Equity and Collaborative Implementation

Recognition of social equity has fundamentally reshaped NBUGS implementation approaches. Contemporary practice increasingly acknowledges that equitable distribution requires explicit attention to socioeconomic factors and community engagement (Azadgar et al., 2025; Boros & Mahmoud, 2021; Li et al., 2025). Social equity strategies strive to ensure equal benefits brought through policy guidance and participatory mechanisms and improve sustainability implementation. Azadgar et al. (2025) comparatively researched Poland, and Italy, linking socioeconomic location with green space layout, and found differences in green space services across income levels. The study points to the potential exacerbation of social and economic inequalities, which puts socially vulnerable communities at higher risk of being affected by climate hazards. Strategies should consider socio-economic factors to address distributive and environmental justice concerns. This equity-focused strategy extends beyond mere spatial redistribution to include participatory design processes that ensure NBUGS align with community needs and preferences. Kato-Huerta & Geneletti (2022) demonstrated that such collaborative approaches not only improve social outcomes but also enhance long-term maintenance and community stewardship of green infrastructure.

5.4 Operation, Maintenance, and Co-Management Solutions

Operation and Maintenance (O&M) practices critically determine the long-term effectiveness of NBUGS. Recognizing the practical challenges of long-term post-construction operation, several completed NBUGS projects now seek to secure sustained benefits by piloting maintenance-mechanism innovations and multi-stakeholder co-management models.

In practice, despite substantial initial investments, many NBUGS projects struggle to sustain ecological benefits due to insufficient maintenance resources, unclear institutional responsibilities, and inadequate funding mechanisms. For instance, poorly maintained green spaces in flood-prone areas of Assam, India, experienced facility deterioration and damaged. This compromised both flood mitigation capacity and resident safety (Bezboruah et al., 2021).

Institutional and collaborative solutions are emerging to address these deficiencies. Cross-departmental coordination frameworks can clarify responsibilities and ensure consistent ecological monitoring. More innovatively, co-management models involving multiple stakeholders show promise. These approaches distribute operational responsibilities among government agencies, residents, and non-governmental organizations, thereby improving resource mobilization and long-term commitment to enhance benefits (Boros & Mahmoud, 2021). The *Biblioteca degli Alberi* urban park in Milan exemplifies successful co-management implementation. The project integrated residents and Non-Governmental Organizations (NGOs) into operational decision-making through community forums and participatory governance mechanisms. This approach sustained operational vitality beyond initial implementation (Boros & Mahmoud, 2021). Bressane et al. (2024) indicated that fostering community involvement in UGS management can promote urban equity and environmental sustainability in emerging economies, particularly through institutional support and transparent information sharing. Some other evidence also suggests co-management models improve both social acceptance and project stability by fostering resident engagement and management (Kingsley et al., 2021; Stenfors et al., 2024).

5.5 Challenges and Limitations of NBUGS Implementation

While NBUGS implementation has achieved notable successes, evolving urban dynamics and data infrastructure gaps present ongoing challenges that require adaptive strategies and collaborative solutions.

5.5.1 Insufficient Data Support

NBUGS design and planning require comprehensive data support (Zarei & Shahab, 2025). Many cities are still developing comprehensive environmental and ecological monitoring networks, and existing data often remains fragmented across departmental data silos, requiring better integration and interoperability. The absence of effective data sharing mechanisms and knowledge sharing platforms between institutions limited environmental and social data effective usage and cross-validated, restrict knowledge dissemination, inhibiting the promotion of NBUGS (Martin et al., 2025; Schröter et al., 2021). In addition, long-term monitoring is lacking, making it difficult to verify the achievement of their initial objectives on a long-term scale (Haase & Dushkova, 2024; C. Xu et al., 2022).

5.5.2 Emerging Urban Problems

Dynamic shifts in urban environments and social patterns continuously bring new challenges requiring adaptive management. Post-pandemic remote work patterns have transformed urban space utilization, creating demand for enhanced community-scale green space supply and quality rather than solely large green spaces in commercial centres (Ernwein, 2020; Geng et al., 2021; Twohig et al., 2022). Growing population aging necessitates integrating barrier-free pathway and health-oriented facilities into NBUGS to ensure social equity (Kabisch et al., 2022; Onose et al., 2020). Developing age-friendly features within existing NBUGS represents a key operational priority. Furthermore, intensifying climate-driven extreme weather events demand continuous evaluation and enhancement of NBUGS resilience and adaptability (Seddon et al., 2020; Zhang et al., 2024).

6. Performance Evaluation of NBUGS

Standard and rigorous evaluation of NBUGS is fundamental to demonstrating their value, guiding investment decisions, and advancing implementation practice. This section examines evaluation methodologies across multiple dimensions, synthesizes evidence of NBUGS impacts, and analyses the strengths and limitations of different approaches. Table 3 organizes key evaluation indicators and tools, along with their typical application scenarios. This table reveals the multidimensionality of current NBUGS evaluation systems and the integration of methods.

Table 2 Key evaluation indicators and tools commonly used in NBUGS evaluation

Dimensions	**Tools / Indicator**	**GIS**	**Sensors**	**ENVI-met**	**i-Tree Suite**	**SWMM**	**InVEST**	**WHO-5**	**Questionnaire**
Environment	**LST**	✓	✓	✓					
	Air Temperature and Humidity	✓	✓	✓					
	Runoff, peak flow	✓		✓	✓	✓	✓		
	Water Quality	✓	✓			✓	✓		
	Air Quality	✓	✓	✓	✓		✓		
	Biodiversity	✓	✓	✓	✓		✓		
Social	**Resident satisfaction and well-being**						✓	✓	✓
	Mental-Health						✓	✓	✓
	Community cohesion, community pride								✓
Economy	**Cost-benefit analysis**			✓	✓		✓		
	Ecosystem service	✓		✓	✓	✓			

	value		
	Property Value	✓	✓

6.1 Environmental Performance Monitoring

In the environmental dimension, the effects of NBUGS on mitigating urban heat islands, hydrological regulation, air quality improvement, and species diversity enhancement are typically evaluated through quantitative indicator monitoring and model simulation (Espinal-Giron et al., 2023; Marando et al., 2019; Preston et al., 2024; Zhang et al., 2024). These methods aim to objectively measure the quantified numerical results of benefits generated by NBUGS and use intuitive data to show the environmental benefits.

Temperature reduction represents one of the most extensively evaluated NBUGS benefits. Assessment methods operate across multiple scales and employ various technologies. For measuring temperature changes, sensor networks, infrared monitoring, and satellite remote sensing are commonly utilized, each with distinct advantages and limitations (Cui et al., 2023; Y. Li et al., 2024; Marando et al., 2022). Ground-based sensor networks and thermal camera provide high temporal resolution and accurate air temperature measurements but are limited by spatial coverage (Chàfer et al., 2020). Satellite remote sensing enables large-scale analysis but typically measures land surface temperature rather than air temperature, potentially overestimating human thermal comfort impacts (Delgado-Capel et al., 2024; Zha et al., 2024). Mobile monitoring enables flexible spatial coverage across different locations, but the dynamic nature of mobile sensors results in temporal inconsistency, limiting the ability to establish reliable temporal patterns (Cui et al., 2023). GIS spatial analysis combined with statistical modelling can identify cooling gradients, revealing that effects typically extend 100-300 meters from green space boundaries (Guo et al., 2024; Yu et al., 2020).

ENVI-met enables scenario testing to simulate the impact of urban green spaces on microclimate, though accuracy depends on detailed parameters (Liang et al., 2023; Rui et al., 2019). Rui et al. (2019) demonstrated the thermal comfort is slightly enhanced with increasing green spaces quantity but also revealed a critical trade-off. More trees may increase the wind blocking effect with a consequent slight increase of pollutant concentration. This study highlights the importance of multi-outcome evaluation rather than single-metric optimization.

Hydrological evaluation focuses on assessing runoff reduction, peak flow attenuation, and infiltration enhancement using plot-scale measurements and watershed modelling (Preston et al., 2024). Comparative evaluation reveals differences across types. Green roofs typically retain 40-70% of annual precipitation (Alemaw et al., 2020). Rain gardens can infiltrate 80-90% during storms but require soil permeability and maintenance (Greksa et al., 2023; Kasprzyk et al., 2022). Permeable pavements show high initial performance but may clog over time (Espinal-Giron et al., 2023; M. Wang et al., 2024). However, few studies systematically compare options under equivalent conditions or examine long-term trajectories.

Air quality assessment focuses on quantifying and comparing pollutant concentrations between green space and urban areas. For example, some studies use air sensor monitoring observed PM_{10} in urban parks at approximately 20 μg/m³, compared to about 25 μg/m³ near roads (Islam et al., 2024). Venter et al. (2024) revisited the link between vegetation and air quality using satellite-derived changes of urban green space and air pollutant concentrations in Europe and United States.

Biodiversity evaluation faces methodological challenges. Camera traps and surveys document species presence but provide limited insight into ecosystem function and species interactions (Beninde et al., 2015; Wooster et al., 2022). NBUGS creates novel ecosystems that differ from natural systems, making it difficult to apply traditional biodiversity assessment frameworks. Biodiversity patterns emerge over years as ecosystems mature, yet most evaluations cover only one or two seasons, insufficient for capturing long-term ecological trajectories (Jeong & Park, 2024).

6.2 Social Surveys and Health Assessments

Since the social benefits of NBUGS are inherently more difficult to quantify than biophysical outcomes, researchers frequently use qualitative and quantitative framework methods combining surveys and interviews to assess their benefits.

Questionnaire surveys are one of primary methods to assess resident satisfaction and subjective well-being. For example, questionnaires can document residents' satisfaction with new NBUGS and perceived improvements in living environment quality (Dash & Paul, 2021; Thapa et al., 2024; Vujcic et al., 2017).

Qualitative methods including interviews and focus groups reveal benefits like community identity and perceived safety but raise representativeness questions (Lee et al., 2024; Navarrete-Hernandez & Afarin, 2023). Social media analysis offers new possibilities to reflect actual community concerns, but skews toward younger, more affluent populations (Jagt et al., 2023; Zhao & Weng, 2024). A critical gap is attention to distributional outcomes and environmental justice. Who benefits and who may be excluded or harmed through green gentrification? Few studies systematically examine variation across socioeconomic groups, raising equity concerns.

6.3 Economic Benefit

Economic evaluation attempts to quantify costs and benefits in monetary terms. Cost-benefit analysis compares lifecycle costs against monetized benefits including energy savings and stormwater cost avoidance (Clemente et al., 2023; Savić et al., 2024). However, most NBUGS benefits lack market prices, requiring non-market valuation techniques with substantial uncertainty. Hedonic pricing infers values from property prices, showing that properties near high-quality green spaces command premiums of several percentage points, but this raises green gentrification concerns (Anguelovski et al., 2018; Bottero et al., 2022; Setiowati et al., 2024). Similarly, Jones et al. (2024) assessed the cooling benefits in 11 UK cities by avoiding labour productivity losses, finding that NBUGS generated £13.97 million benefits.

Quantitative models and tools are frequently employed to assess ecosystem value. H. Zhao et al. (2023) used the i-Tree Eco model to quantify the ecological and economic benefits of urban forests, revealing differences across greening configurations and providing quantitative evidence for urban forest planning. Hamel et al. (2021) proposed an InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) method to quantify and map the hydrological regulation, carbon sequestration, biodiversity habitat, and socioeconomic benefits. However, the outputs of these ecosystem services tools are highly sensitive to input parameters, which are often unavailable or estimated crudely.

6.4 Limitations and Challenges of NBUGS Evaluation

Although recent studies have confirmed the positive effects of NBUGS across multiple domains, existing evaluation practices face three fundamental challenges.

First, most evaluations adopt a narrow, single-dimensional focus. Studies predominantly examine environmental benefits, concentrating on easily quantifiable indicators such as temperature reduction, stormwater runoff mitigation, or air pollutant removal, while neglecting social and economic dimensions. This narrow focus obscures potential synergies and trade-offs among different benefit categories, undermining decision-makers' ability to assess the integrated value proposition of NBUGS interventions.

Second, the absence of standardized evaluation frameworks hinders cross-study comparison and knowledge synthesis. Different studies employ disparate indicators and methodologies based on context-specific objectives. For instance, heat island mitigation studies variously report land surface temperature reductions, air temperature changes, or thermal comfort indices (Guo et al., 2024; Marando et al., 2019), making horizontal comparisons across case studies problematic. This fragmentation impedes the transferability of findings across different urban contexts and limits the development of NBUGS.

Third, a critical temporal mismatch exists between evaluation timescales and benefit realization. NBUGS generate benefits that accumulate and evolve over extended periods. However, most evaluations span only one or two growing seasons, failing to capture these long-term dynamics. The absence of longitudinal monitoring undermines understanding of benefit trajectories and prevents accurate lifecycle cost-benefit analyses.

7. Further Directions

This systematic literature review indicates that NBUGS have demonstrated substantial multidimensional benefits while revealing critical gaps in current research and practice. Addressing these limitations and maximizing potential of NBUGS require systematic advances across four interconnected domains: (1) responding to evolving urban demands through comprehensive design, (2) developing integrated planning approaches that manage synergies and trade-offs, (3) establishing dynamic management systems enabled by digital technologies, (4) creating standardized evaluation frameworks that facilitate knowledge transfer.

7.1 Responding to Emerging Urban Challenges as New Demands

The rapid transformation of urban social dynamics and environmental conditions necessitates fundamental reconsideration of NBUGS design priorities and spatial configurations. Future NBUGS design and construction need to address increasingly complex new urban challenges and emerging needs. This section identifies three research direction where NBUGS could adapt to emerging challenges: spatial restructuring driven by post-pandemic behavioural changes, climate resilience under accelerating extreme weather events, and distributional equity across diverse demographic groups.

7.1.1 NBUGS Restructuring in Emerging Work Patterns

The rise of flexible work arrangements has fundamentally altered patterns of urban green space utilization, shifting demand from centralized parks in commercial districts toward accessible community-scale green infrastructure (Yamazaki et al., 2021). However, existing research inadequately examines how these behavioural shifts should inform NBUGS planning strategies. To address these new challenges, future research should examine how changes in resident behaviour patterns affect the use of green spaces and inform urban green space reconfiguration. These studies would provide empirical foundations for post-pandemic urban green space reconfiguration aligned with emerging mobility and lifestyle patterns.

7.1.2 Climate Resilience-Oriented Multifunctional NBUGS Design

Global warming is occurring faster than at any time on record (Hansen et al., 2025). Increasingly extreme heat waves and storm also impose severe stress on NBUGS capacity for climate regulation and disaster buffering (Debele et al., 2023). Future research should prioritize climate resilience-oriented multifunctional design that simultaneously addresses several urban climate challenges, such as heat mitigation, stormwater management, and drought tolerance. These advances would transition NBUGS from single-benefit interventions to comprehensive climate adaptation infrastructure capable of withstanding intensifying environmental stresses.

7.1.3 Equity-Centred NBUGS Planning: Addressing Structural Inequalities

Current NBUGS interventions often exacerbate existing socioeconomic inequalities through uneven distribution and green gentrification processes, yet most planning frameworks lack explicit equity mechanisms (Kato-Huerta & Geneletti, 2022). Future research must embed distributional justice considerations throughout NBUGS planning, implementation, and evaluation. As the global population enters an aging phase with significant demographic changes, NBUGS construction also needs to consider the needs of different groups. Kabisch et al. (2022) highlighted the urgency of addressing green space equity in aging societies, yet operational frameworks remain underdeveloped. Future research should investigate green space equity and access rights, such as targeted investment prioritization in underserved neighbourhoods, prevent green gentrification policies, and universal design principles ensuring accessibility across age and ability spectra. These insights would better guide policy formulation and green space renewal strategies, ensuring NBUGS enhance rather than undermine urban equity.

7.2 Systematic NBUGS Development: From Isolated Interventions to Integrated Solutions

The multidimensional impacts documented in Section4 demonstrate that NBUGS generate complex effects exhibiting both synergies and trade-offs across environmental, social, and economic domains. However, current practice primarily pursues single-objective optimization, failing to use synergistic potential while causing unintended consequences. Addressing systemic urban challenges necessitates transitioning from isolated interventions toward integrated strategy portfolios (Jagadisan, 2024). This section advocates for research advancing systematic NBUGS development through multi-benefit optimization and synergy-trade-offs dynamics management.

7.2.1 Multi-benefit Optimization Through Interdisciplinary Integration

Existing research reveals that integrated NBUGS interventions combining multiple elements consistently outperform single-component approaches (Twohig et al., 2022). Yet systematic frameworks guiding optimal integration remain absent. Future research should view urban nature as an integrated, multi-benefit system. To achieve this, studies should develop interdisciplinary collaborative methodologies that jointly optimize NBUGS configurations across ecological, social, and economic objectives.

Critically, such optimization must extend beyond biophysical performance metrics to incorporate governance feasibility, fiscal sustainability, and community acceptability. This requires interdisciplinary collaboration mechanisms across ecology, urban planning, government agencies, environmental engineering, and sociology can jointly develop intervention strategies.

7.2.2 Understanding and Managing Synergies and Trade-offs

NBUGS possess multifunctional attributes, such as climate regulation, public health promotion, biodiversity enhancement, and urban economic attractiveness improvement. However, these functions often have inherent coupling and potential conflicts. For example, dense planting can reduce regional temperatures but impede ventilation (Rui et al., 2019). Similarly, urban parks can improve the environment and increase surrounding property values but cause ecological disturbances and green gentrification risks. Failing to anticipate trade-offs can undermine NBUGS effectiveness and social acceptability. (Kato-Huerta & Geneletti, 2022). Future research should identify these potential synergistic and trade-offs. Through multi-objective optimization models could incorporate environmental indicators, social indicators and economic indicators to construct intervention strategy combinations that can maximize benefits and manage risks.

7.3 Dynamic Smart Management of NBUGS

NBUGS have characteristics of long-life cycles and slow physical changes, but cities facing rapidly evolving and dynamic challenges (Weiskopf et al., 2020). Population migration, climate fluctuations, industrial transitions, and changing resident needs can alter the role and usage patterns of NBUGS in the short term. However, only a few previous research considered operation strategies and urban dynamic change risks. This temporal mismatch necessitates transitioning from static maintenance strategies toward dynamic adaptive management systems capable of responding to environmental changes and evolving urban contexts. This section identifies three research frontiers: data-driven management platforms leveraging digital technologies, data standardization enabling interoperability, and co-management governance models fostering community stewardship.

7.3.1 Data-Driven Management Platforms

The proliferation of Internet of Things (IoT) sensors, remote sensing technologies, and artificial intelligence offers unprecedented opportunities for real-time NBUGS monitoring and adaptive management. These methods have been widely used in urban infrastructure management (Kandt & Batty, 2021). However, these technological capabilities remain underutilized in NBUGS governance, with most management relying on periodic manual inspections. Future research should investigate implementation of integrated data-driven management platforms combining multiple information streams, such as big data analysis, drone surveys, and Machine Learning. Integrating these data streams within centralized platforms would enable evidence-based dynamic decision-making regarding maintenance priorities and resource allocation.

Furthermore, digital twins (DTs) present transformative potential for NBUGS management. DTs can simulate ecological performance and predict future states under different management scenarios, which can support cross-spatiotemporal decision simulation (de Koning et al., 2023; Khan et al., 2025). Successfully implementing data-driven platforms could fundamentally transform NBUGS from passively maintained infrastructures to actively managed adaptive infrastructure.

7.3.2 Data Standardization and Interoperability

Establishing management platforms and effective data-driven management requires integration of heterogeneous data sources including spatial data, environmental monitoring, infrastructure information, and social feedback. However, current urban data systems typically operate in isolated silos using incompatible formats, impeding integration (Ogunkan & Ogunkan, 2025; Raghavan et al., 2020). Future research should explore how to build standardized systems for collecting and sharing data. This requires studies addressing technical infrastructure, institutional collaboration between agencies, and governance frameworks for data sharing. Importantly, standardization should not impose rigid uniformity but rather enable flexible integration of diverse data sources. Integrated data systems would support smarter decisions for dynamic smart NBUGS management.

7.3.3 Co-management and Community Co-governance of NBUGS

Successful long-term NBUGS operation increasingly relies on collaborative governance models distributing responsibilities among government agencies, community organizations, and residents. The *Biblioteca degli Alberi* case in Milan exemplified how participatory governance mechanisms sustain operational effectiveness while enhancing social acceptance (Boros & Mahmoud, 2021). However, current systematic understanding of conditions enabling successful co-management remains limited. Future research should establish effective co-governance models, identifying how to coordinate responsibilities among government, professionals, and community members. Further studies should also ensure that community co-governance models reach and empower marginalized residents rather than only engaging affluent or special groups. Understanding effective co-management design would address governance challenges threatening long-term NBUGS sustainability while enhancing social cohesion benefits.

7.4 Unified and Standardized NBUGS Evaluation Systems

With accelerating urbanization and the prominence of climate change issues, NBUGS are gradually becoming crucial methods of addressing multidimensional urban challenges (Seddon et al., 2020). Despite their importance, current NBUGS evaluation practices remain limited. Assessments lack standardized frameworks for cross-study comparison, and temporal mismatch between short-term assessments and long-term benefit realization. This section advocates for three advances: developing standardized indicator systems, establishing long-term monitoring mechanism, and creating open data-sharing platforms facilitating global knowledge exchange.

7.4.1 Standardized and Modular Evaluation Indicators

The International Union for Conservation of Nature and Natural Resources (IUCN) and the European Commission (EC) have successively proposed comprehensive evaluation systems covering environmental, social, and economic domains. Although they have certain universality, specific implementation still needs to consider different local contexts.

Future research should develop modular indicator framework: (1) universal core indicators applicable globally across all NBUGS types, enabling cross-site comparisons; (2) context-specific modules addressing regional priorities such as disaster resilience in climate-vulnerable regions, or cultural heritage preservation in historic cities; and (3) project-specific indicators tailored to unique intervention objectives or stakeholder priorities. Urban policymakers could customize specific modules according to their own needs to ensure the localized adaptability of evaluation indicators.

7.4.2 Long-term Benefit Monitoring

Most current evaluations are limited to short-term before-and-after comparisons, lacking tracking long-term evolutionary effects and cumulative benefits of NBUGS interventions (Augusto et al., 2020). This temporal limitation hinders understanding of how green space benefits develop over time. Future research should establish decade-scale longitudinal monitoring systems that track NBUGS impacts across multiple dimensions, while capturing temporal dynamics of benefit accumulation. These longitudinal frameworks would provide empirical evidence for evaluating long-term effectiveness, establishing causal mechanisms, and supporting policy decision making. Ultimately, such approaches would transform NBUGS evaluation from one-time assessments to dynamic understanding of how green infrastructure shapes urban systems over time.

7.4.3 Open Data-Sharing Platforms

Open data sharing platforms are essential for advancing NBUGS evaluation and implementation globally. Future research should establish an open database like IPCC climate model database and WHO health indicator systems, that save and share NBUGS project data worldwide in standardized formats. Such platforms would enable cross-regional analysis and knowledge synthesis, allowing urban planners and policymakers to draw on systematically organized global experiences rather than relying on fragmented case studies. Beyond facilitating knowledge access, open data platforms would catalyse inter-city collaboration and technical exchange in NBUGS governance. EC indicated that these platforms would also facilitate outcome sharing, method reuse, and knowledge accumulation, ultimately pushing NBUGS implementation toward more refined and intelligent directions. Successful establishment of open data platforms would fundamentally transform NBUGS from locally contextualized practices toward globally connected knowledge networks.

8. Conclusion

This systematic review synthesizes evidence from 128 peer-reviewed empirical studies published between 2016 and 2025, documenting how NBUGS have evolved from an emerging concept to a mainstream urban sustainability strategy. The exponential growth in publications since 2020, confirms NBUGS' recognition as critical infrastructure for addressing interconnected urban challenges. However, the geographical concentration of research in economically developed countries and regions, while climate-vulnerable developing areas remain underrepresented, reveals a significant mismatch between research efforts and global needs.

Substantial studies demonstrate that NBUGS deliver multidimensional benefits across environmental, social, and economic domains. Environmentally, they provide effective strategies for climate regulation, stormwater management, and biodiversity enhancement. Socially, they contribute demonstrably to public health, well-being, and community cohesion. Economically, they frequently represent cost-effective solutions than traditional grey infrastructure while generating tangible property and ecosystem services values. The interconnected nature of NBUGS impacts creates both opportunities and challenges. Property value increases may drive green gentrification and displace vulnerable populations. Dense vegetation improves cooling but may impede air circulation. Community gardens strengthen social bonds while potentially excluding marginalised groups. These cascading effects underscore that NBUGS should not be evaluated solely through single-dimensional metrics but require systemic assessment frameworks that capture multidimensional interactions.

NBUGS implementation practice has evolved from isolated project-based interventions to systematic approaches, supported by geospatial technologies, multi-criteria decision frameworks, and simulation tools that enable practitioners to optimize site selection, predict performance, and balance multiple objectives. Furthermore, a wide range of evaluation tools and methodologies are now available for NBUGS assessment. These methods can be applied to monitor multiple scales, and to capture environmental performance, social impacts, and economic returns across project lifecycles.

However, critical limitations persist in current NBUGS implementation and evaluation. First, the predominance of short-term evaluations fails to capture long-term ecosystem maturation and maintenance dynamics. Second, fragmented evaluation systems with inconsistent indicators and methodologies prevent meaningful cross-site comparisons and knowledge transfer. Third, insufficient attention to operational management and adaptive governance threatens the sustainability of implemented projects, as evidenced by ecological degradation in inadequately maintained sites.

Future research direction of NBUGS should consider from four domains identified in this review. First, responding to emerging urban challenges through climate resilience-oriented design and equity-centred planning. Second, transitioning from isolated interventions to integrated solutions that systematically optimize synergies and manage trade-offs across benefit dimensions. Third, developing dynamic smart management systems leveraging IoT sensors, digital twins, and real-time monitoring for data-driven optimization. Fourth, establishing unified standardized evaluation systems with modular indicator frameworks, long-term monitoring mechanism, and open data-sharing platforms.

This review advances NBUGS scholarship by providing the synthesis of multidimensional impacts based on empirical research from the past decade, systematically documenting the evolution of implementation tools and evaluation methodologies while identifying their current limitations, and establishing a structured framework for future research priorities. For policymakers and practitioners, the imperative is to embed NBUGS within integrated urban planning strategies. Cities must transition from viewing green spaces as aesthetic amenities to recognizing them as essential adaptive infrastructure requiring dynamic management systems. They should also explicitly link green infrastructure with housing, transport, and public health policies while fostering participatory governance models. As cities face accelerating climate impacts and evolving social dynamics, NBUGS must transition from isolated interventions to components of systemic urban transformation strategies. Innovative and systematic NBUGS strategies can create cities not only greener and more resilient, but also more equitable and inclusive.

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Building Urban Resilience Through Nature: A Systematic Review of Urban Green Spaces as Nature-based Solutions

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