Socio-Ecological Practice Research (2024) 6:5–20
https://doi.org/10.1007/s42532-024-00178-w

REVIEW ARTICLE

A bibliometric assessment of the science and practice of blue–green space (BGS): hot spots, lacunae, and opportunities

Bo Mu[1] · **Ruting Zhao**[1] · **Yang Liu**[2] · **Enkai Xu**[2] · **Yali Zhang**[1] · **Hong Wei**[2] · **Guohang Tian**[2]

Received: 9 November 2023 / Revised: 25 January 2024 / Accepted: 25 January 2024 / Published online: 21 February 2024

Abstract
Blue–green space (BGS) is an important component of the Earth's environment, and BGS research and practice have become an increasingly important part of climate change adaptation and mitigation. In this review article, we conducted a bibliometric assessment on the science and practice of BGS worldwide. Our results showed that (1) the number of BGS studies has been growing rapidly since 2017, and the intensity of international collaboration has increased markedly; (2) BGS research hot spots were ignited by and focused on environment problems and evolved over time. Examples include, but are not limited to, boosting the composite functions and synergistic effects of BGS in climate change adaptation and mitigation (particularly stormwater management and thermal environment regulation), enhancing ecosystem services (biodiversity and carbon), and promoting human health (physical and mental); (3) the collaborative planning and system construction of BGS will be a major development trend in the future; and (4) research on synergistic mechanisms, collaborative planning, and BGS spatial pattern optimization has largely been theoretical, and there is a shortage of empirical quantitative research and there are few real-world examples of BGS in socio-ecological practice. These set the stage for further advancement of BGS science and practice.

Keywords Blue–green space · Bibliometrics · Research progress · Hot spot visual analysis

1 Introduction

Urbanization has extensively impacted the global ecological environment, leading to increasingly frequent extreme climate events [Howe (2021), p. 3 of 17], severe degradation of natural habitats [Namkhan et al. (2022), p. 3], and significant loss of biodiversity [Lv et al. (2023), Sun et al. (2022), p. 2 of 10], among other effects. Issues related to human settlements and health have become increasingly prominent. For decades, researchers and planners have been studying the mechanisms of human-mediated disturbance to natural environments [Gu et al. (2022), pp. 1–2]. They have also been exploring restoration techniques for damaged habitats [Yuan et al. (2022), pp. 3–4, Kuo et al. (2021), pp. 2–9] and ways to optimize human-dominated environments [Guo et al. (2021), p. 2, Du and Lin (2023), p. 3]. As vital components of the biosphere and ecosystem, blue spaces (water bodies) and green spaces (vegetation), collectively known as blue–green spaces (BGS), have emerged as key focal points for ecology and spatial planning researchers. The influence and interaction mechanisms of the blue and green spaces on the environment [Fan et al. (2022), pp. 8–11], climate [Zhou et al. (2023), p. 10 of 11] and human health [Zhou et al. (2022), pp. 5–6] have been continuously studied and confirmed.

In the past decade, research on blue and green spaces has evolved from viewing them as separate landscape elements (green spaces or water bodies) [Wolch et al. (2014), Zhang et al. (2014)] to considering their integration as blue–green spaces (BGS) within an integrated ecological infrastructure [Sanchez and Govindarajulu (2023), p. 1 of 7]. Concepts such as blue–green space (BGS), blue–green landscape (BGL), and blue–green infrastructure (BGI) have been proposed to facilitate this integration. Research and practice now focus on the spatial relationships [Xue et al. (2022),

✉ Hong Wei
weihong-la@henau.edu.cn

✉ Guohang Tian
tgh@henau.edu.cn

1 College of Resources and Environmental Sciences, Henan Agricultural University, Zhengzhou 450002, China

2 College of Landscape Architecture and Art, Henan Agricultural University, Zhengzhou 450002, China

Sander and Zhao et al. (2015), p. 4 of 16], overall landscape effects [Fan et al. (2022), p. 9, Li et al. (2021)], synergistic mechanisms [Shi et al. (2020), Wu et al. (2018), p. 658], and the development of an integrated planning approach for BGS, BGL, and BGI [Sanchez and Govindarajulu (2023), p. 4, Puchol-Salort et al. (2021), p. 8].

Research on using BGS for heat island mitigation [Yu et al. (2020), p. 5], biodiversity enhancement [Donati et al. (2022), p. 5], and human health promotion [Labib et al. (2020), pp. 13–15] has been the subject of several reviews. However, most of these reviews have focused on limited aspects of BGS and lack comprehensiveness. In this paper, we aim for a more systematic understanding of the current state of BGS research. Using bibliometrics, we sorted and summarized the available publications on BGS, BGL, and BGI. Taking blue and green space as a single, integrated entity, we have summarized the current state of BGS research and progress achieved. In addition, we analyze the global key ecological issues that may be affected by BGS. We also outline development trends in the integrated development of BGS and discuss the future needs of BGS research.

1.1 Definitions and connotations of BGS/BGL/BGI

Blue–green space (BGS) defines a specific area characterized by water bodies (blue space) and vegetated areas (green space) [Sander and Zhao (2015), p. 194]. This concept focuses on a distinct area featuring various land surface attributes unified by similar visual hues. Blue–green landscape (BGL) is defined as a landscape type consisting of "blue" elements (including oceans, lakes, rivers, fountains, and streams) and "green" elements (such as parks, gardens, and forests) [Finlay et al., (2015), pp. 97–98]. This term highlights a complex landscape amalgamating two distinct landscape schemes. Blue–green infrastructure (BGI) is considered an interconnected network of both natural and engineered landscape components, incorporating water bodies as well as green and open spaces [Lamond and Everett (2019), p. 1 of 10]. It underscores a multifunctional system that adopts more nature-friendly approaches to address urban ecological issues. These issues include managing urban flood risks, reducing heat island effects in cities, and boosting biodiversity in and around urban environments [Oliveira et al. (2022), p. 2 of 16]. While these three concepts are fundamentally rooted in the elements of blue water and green vegetation, they have been progressively refined and enhanced in both form and function. Indeed, BGL and BGI can be viewed as advancements and extensions of BGS in terms of both their structure and utility. Consequently, in this paper, all research related to these three concepts is collectively addressed under the term "BGS."

1.2 The wide application of bibliometrics

Bibliometric analysis has become a crucial method for encapsulating the intellectual framework of various research fields [Donthu et al. (2021), p. 288]. Its capacity to process substantial amounts of scientific data, coupled with mapping analysis tools, enables the visualization of knowledge, thereby facilitating a rapid grasp of a research field's developmental context [Liu et al. (2021), p. 2 of 14]. The popularity of the bibliometric methodology has surged recently, largely owing to the widespread availability and efficacy of bibliometric software [Donthu et al. (2021), p. 295]. Three bibliometric software packages are often used together: CiteSpace, VOSviewer and Scimago Graphica [Shen et al. (2023), p. 20]. CiteSpace was developed for use in field analysis, frontier analysis, and evaluation of progress in scientific research progress [Zhao et al. (2022), p. 2, Li et al. (2022), p. 3]. VOSviewer was developed by Leiden University in the Netherlands [Eck et al. (2010)]; it analyzes and presents a clear clustering network and node connections [Tamala et al. (2022), p. 2]. This software can analyze the problems in the research field by means of cluster view, label view, density view, etc. Scimago Graphica conducts analyses through graphical description [Wei et al. (2022), p. 3].

In this study, bibliometric analysis is employed to systematically examine the structure and dissemination of knowledge within BGS, BGL, and BGI. The objective is to provide a comprehensive overview and visualization of these areas. Additionally, the study aims to delve into the research status and trends in BGS, identifying emerging themes and shifts in focal points through bibliometric analysis. Ultimately, the goal is to derive more effective optimization strategies and development directions for BGS.

2 Methods

2.1 Literature retrieval in WOS using three keywords

The Web of Science (WOS) is a widely utilized database for bibliometric analysis, encompassing a comprehensive collection of published papers indexed in SCI, SSCI, A&HCI, CPCI, and BKCI. Recognized as a highly authoritative citation indexing platform, it accurately reflects research advancements across various fields. Consequently, this study also selected WOS as the primary source for literature data. A preliminary search was conducted in this database using "blue green space," "blue green landscape," and "blue green infrastructure" as distinct search keywords. Under the condition of publication time (default 1985 until the final retrieval date), retrieval results were intersected, and the deadline chosen for literature retrieval was December 31, 2022. We limited the literature types to "articles" and "reviews" and specified the publication language as English.

2.2 Literature selection according to the established filtering criteria

Our initial searches yielded 2898 papers. Using the titles and abstracts of preliminary search papers as filtering criteria, 1707 duplicate papers were deleted because of the similarity of the three concepts. In total, 871 documents that failed to meet the screening criteria (similar research fields and research objects containing both blue and green spaces) were eliminated from the remaining 1191 papers. The research fields covered in this study are specifically confined to Environmental Science, Environmental Studies, Green Sustainable Science Technology, Public Environmental Occupational Health, Ecology, Remote Sensing, Urban Studies, Regional Urban Planning, and Biodiversity Conservation. Consequently, the final research sample selected for review consisted of 320 papers. After a thorough examination of the content of the remaining papers, an additional 30 papers were included based on references checks. Ultimately, 350 documents were selected that focused on combining blue and green space as a unified object for structural or functional research. The steps for paper selection are depicted in Fig. 1.

2.3 A bibliometric analysis procedure using three softwares

We employed three bibliometric software tools (CiteSpace 5.1.R7, VOSviewer v1.6.18, and Scimago Graphica) to conduct a quantitative analysis of the 350 selected papers. The analytical results included basic bibliometric information and clustering. The specific methods and steps we adopted were as follows:

(1) Based on the WOS database and final literature sample, CiteSpace 5.1.R7 was used to analyze the basic information from each publication, including keywords, authors, institutions, and countries represented. Following screening and verification, the final dataset for bibliometric analysis comprised 350 papers published between 2012 and 2022. The time slice was set to 1 year.
(2) Using VOSviewer v1.6.18 and Scimago Graphica software, the distribution characteristics of the countries represented in the papers and the extent of cooperation intensity between different countries were analyzed. Results from VOSviewer v1.6.18 were exported to Microsoft Excel to summarize the number of papers issued by each country. Then these results were imported into the Scimago Graphica software to create a country distribution map and the country cooperation intensity map through data-matching adjustment.
(3) CiteSpace 5.1.R7 was used to cluster documents with strong co-citation relationships and to analyze their timelines. This process yielded 130 nodes, 368 links, and seven content clusters. Nominal terms were extracted from the titles, keywords, and abstracts of the clustered documents, and used to name the cluster content.
(4) Finally, VOSviewer v1.6.18 was used again to analyze research hot spots derived from the seven content clusters identified in the previous step, extract the high-frequency vocabulary used in each cluster, and analyze the strength of connections between them. Subsequently, we summarized the prominent research

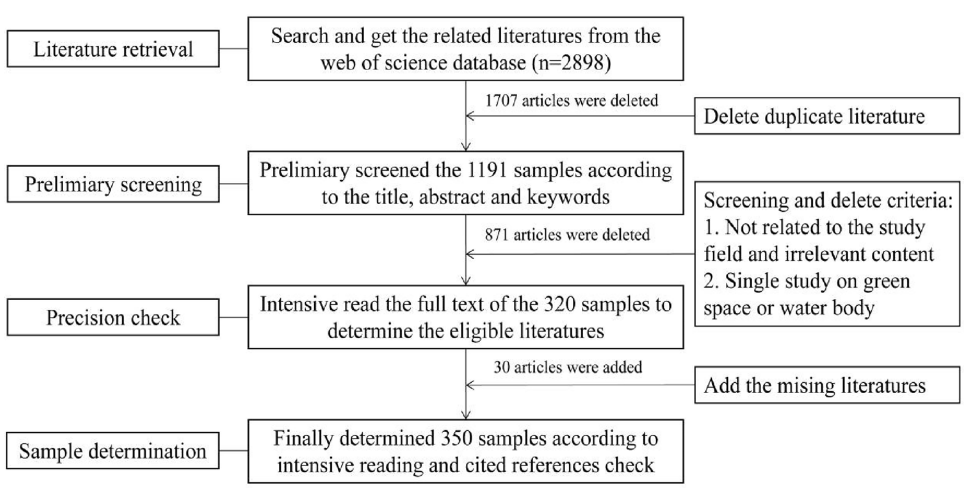

Fig. 1 Literature selection steps and results

directions in BGS research and identified the key scientific issues that require future study.

3 Results

3.1 The quantitative analysis of literature in time series and different countries

Figure 2 depicts a clear upward trend in BGS research over the past 10 years. The change process can be divided into three stages: early (2012–2014), midterm (2015–2017), and recent (2018–2022). During the early stage (2012–2014), the number of published papers was very few, yet these papers received a relatively high number of citations. These initial studies were foundational and significantly influenced subsequent BGS research. In the midterm stage (2015–2017), the number of papers increased, though the annual publication rate remained low. In contrast, the recent stage (2018–2022) witnessed a dramatic surge in BGS research, with the annual number of published papers rising from 22 in 2018 to 150 in 2022.

Assessments of publication countries and their collaboration intensity (Fig. 3) reveal that BGS research is

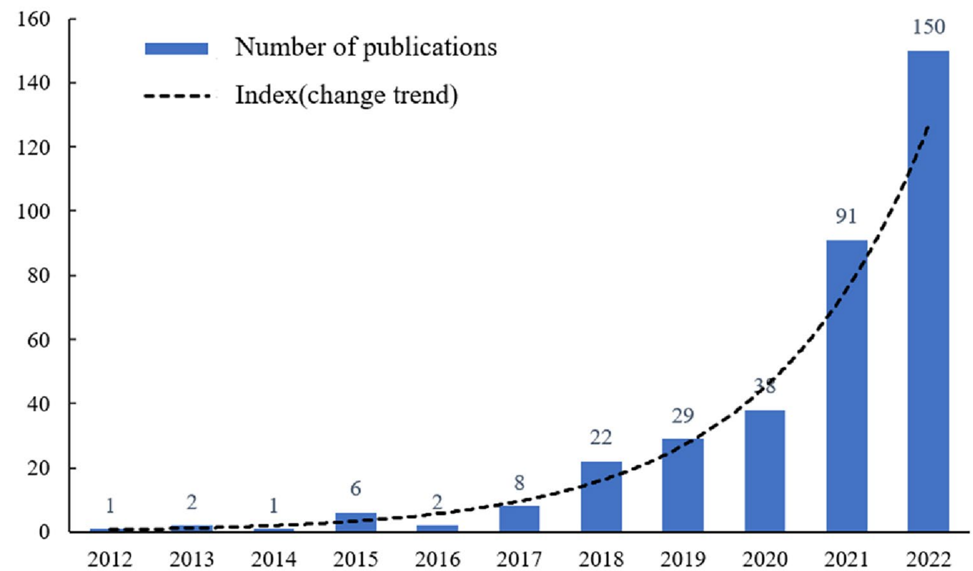

Fig. 2 Yearly changes in the number of publications related to BGS

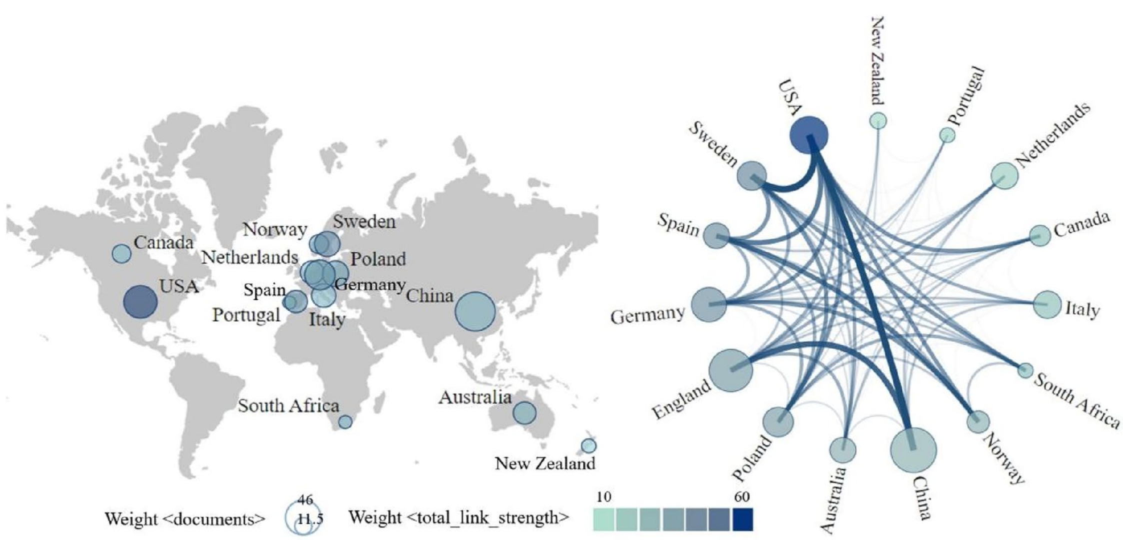

Fig. 3 Distribution of publication countries **a** and their collaboration intensity **b** in BGS research (the size of the circles varies proportionally with the number of papers published by each country, ranging from small to large. The colors intensity and thickness of the lines vary from weak to strong, indicating the strength of cooperation between countries)

conducted extensively on a globally scale, with significant contributions from China, the USA, and European countries. The countries with the highest number of published papers are China (71 papers), the UK (65 papers), and the USA (53 papers). Germany (38 papers), Poland (31 papers), and Sweden (24 papers) ranked fourth to sixth in terms of publication numbers. Papers from these counties accounted 80.57% of the total publications and also displayed the greatest collaborative intensity, both within their own institutions and with other countries.

3.2 The collaboration network of publishing institutions and authors

Table 1 shows the top-ten paper publishing institutions, authors, and countries. The University of Exeter in the UK, Professor Erik Andersson from the University of Helsinki, and China rank first in their respectively categories. Professor Erik Andersson's primary focus is on the role of BGI in providing ecosystem services, as well as on spatial analysis methods related to BGI proportion and boundaries. He has also collaborated extensively with Professors Timon Mcphearson and Dagmar Haase.

According to the collaboration network of publishing institutions and authors (Fig. 4), early collaborations had

Table 1 Statistics of the top-ten paper publishing institutions, authors, and countries

Institutions (Top 10)	Number of articles	Authors (Top 10)	Number of articles	Countries (Top 10)	Number of articles
University of Exeter	11	Erik Andersson	6	China	71
Humboldt University	7	Timon Mcphearson	5	England	65
Helmholtz Centre for Environmental Research	6	Payam Dadvand	4	USA	53
Chinese Academy of Sciences	5	Berry Gersonius	4	Germany	38
Stockholm University	5	David N Barton	3	Poland	31
The New School	5	Mireia Gascon	3	Sweden	24
Lund University	5	David Martinez	3	Italy	20
University of Nottingham	5	Dagmar Haase	3	Spain	18
University of Leeds	5	Sara Borgström	3	Australia	16
East China Normal University	5	Kim Vercruysse	3	The Netherlands	15

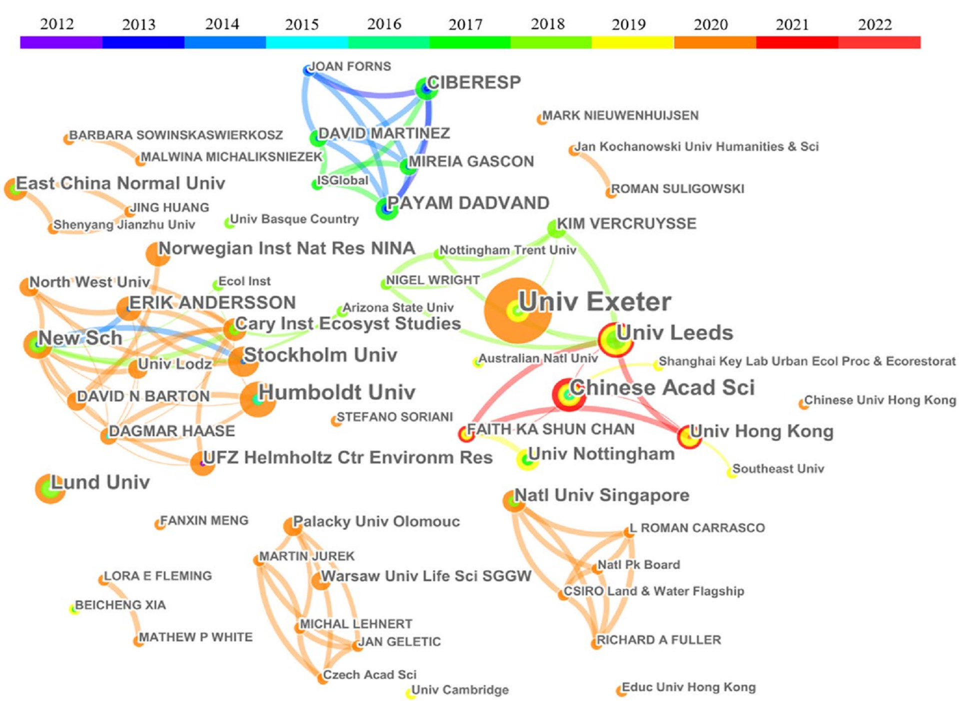

Fig. 4 Analysis of the cooperation network between publishing institutions and authors (the size of each dot is proportional to the number of documents published by each author, and the lines represent cooperative relationships)

a significant impact on subsequent literature. During the midterm period (2015–2017), there was an increase in the number of collaborating institutions and authors. A key collaboration in this period involved New School University in New York City and the Cary Institute of Ecology, focusing on developing nature-based solutions to climate change challenges. The impact of this collaboration persisted until 2020. In the later period (2018–2022), collaboration between institutions and scholars increased markedly. Notable institutions during this period included the Universities of Exeter and Leeds in the UK, Humboldt University in Berlin, Germany, and the Chinese Academy of Sciences. The Hong Kong University and Southeast University in China had notably close cooperative relationships with the universities of Leeds and Exeter. East China Normal University and Shenyang Architecture University also collaborated with Peking University School of Public Health. Overall, research conducted at Chinese institutions forms the core of BGS research. Currently, the most active research collaboration is between the Chinese Academy of Sciences and the University of Exeter.

3.3 The frequency and popular time analysis of keywords in published articles

As shown in Table 2, the most frequently occurring keyword in the sample literature is "city," appeared 50 times. This indicates that BGS research primarily targets urban environments, with less focus on rural areas. Secondly, studies on the ecological services of BGS, as well as its value in promoting human movement and health, began appearing frequently starting in 2017. Research on climate change, biodiversity, disaster exposure, and resilience restoration, although fewer in number, emerged around 2019. These findings suggest that research on the added value and multifunctionality of BGS has expanded over time, paralleling the growing awareness of the challenges faced by human settlements.

3.4 The cluster and visual analysis of research hot spots

As shown in Fig. 5, research on BGS has concentrated on five hot spots: ecosystem services, environmental and climatic challenges, stormwater regulation and storage, human health and well-being, and urban planning. These research hot spots have evolved over time from focusing on single issues to more complex, interconnected studies, gradually expanding into broader fields. The BGS knowledge network map demonstrates this shift from research initially centered on basic structures and single service functions of individual spaces to studies on network structures and complex functions involving both

Table 2 Statistical analysis of the frequency and popular year of keyword appearance

Order	Frequency*	Keywords	Popular year*
1	50	City	2017
2	41	Ecosystem service	2017
3	23	Green infrastructure	2017
4	23	Impact	2018
5	18	Benefits	2018
6	17	Management	2017
7	16	Blue–green infrastructure	2018
8	15	heat island	2019
9	15	Nature-based solution	2017
10	14	Urban	2018
11	14	Physical activity	2015
12	13	Health	2017
13	13	Infrastructure	2017
14	13	Vegetation	2019
15	12	Mental health	2018
16	12	Climate change	2018
17	12	Air pollution	2018
18	12	Temperature	2020
19	11	Land use	2018
20	11	Stormwater management	2019
21	10	Design	2019
22	10	Areas	2019
23	10	Climate	2020
24	10	Urban planning	2020
25	9	Urbanization	2017
26	9	Restoration	2019
27	9	Challenges	2019
28	8	Biodiversity	2020
29	8	Framework	2020
30	8	Exposure	2020

*Frequency, total number of times the keywords appears in the retrieved documents, which highlights the researchers to that keywords. Year, average year in which the keywords appears in the retrieved documents, reflecting the relative popularity of the keywords

spaces as essential urban infrastructure. Ultimately, research aims have progressed toward the layout and planning of BGS, following a logical sequence of identification, analysis, and problem-solving. However, research on practical BGS planning is still in its early stages and remains relatively limited.

Based on the analysis of hot spot clustering and their interrelationships in BGS research, we summarized and analyzed progress in four key areas of BGS research: climate change adaptation and mitigation, promotion of human health, enhancement of ecosystem services, and spatial planning practice.

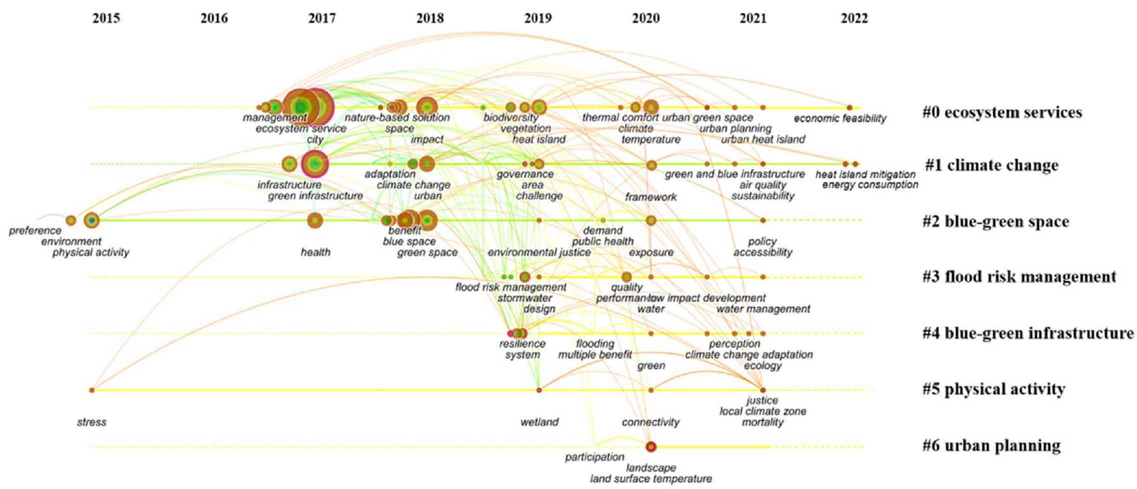

Fig. 5 Visual analysis of the development of research content and hot spots over time

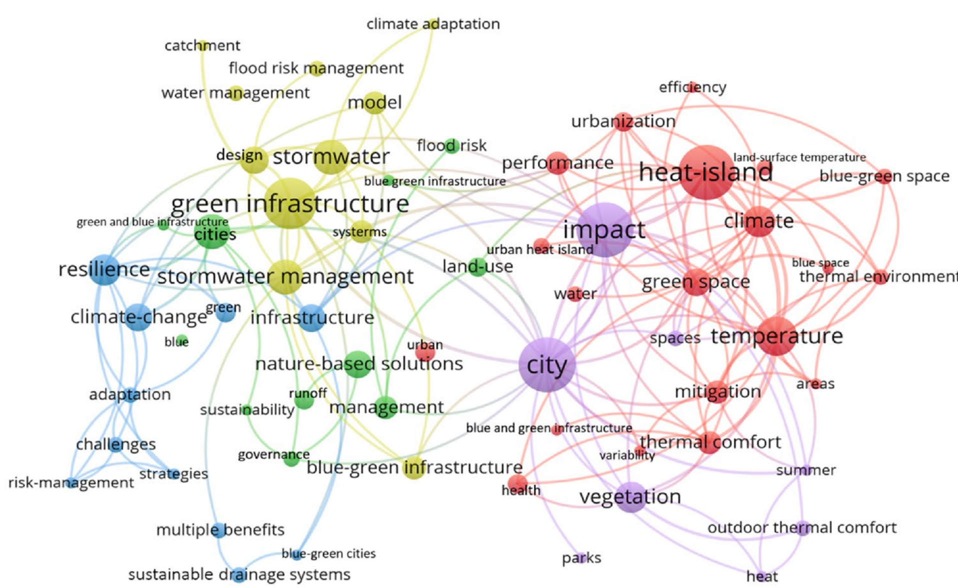

Fig. 6 Hot spot visual analysis of BGS research in climate change adaptation and mitigation

3.4.1 Progress and deficiencies of BGS research in climate change adaptation and mitigation

Research on the role of BGS in climate change adaptation and mitigation can be clustered into 61 keywords (Fig. 6), of which "green infrastructure," "impact," "heat island," "city," and "stormwater management" have the largest node degree, the highest frequency of occurrence, and the strongest connections to other keywords. The scope of this research is primarily focused on the urban scale, with particular emphasis on the ability of BGS to mitigate temperatures in urban heat islands and manage urban stormwater. For example, research on urban heat island effects have revealed that blue and green components possess distinct cooling paths, interaction effects, and mitigation mechanisms during rapid urbanization [Yang et al. (2020), p. 10, Gunawardena et al. (2017), pp. 1050–1052]. The synergistic cooling achieved by integrated BGS is increasingly recognized as a promising approach to mitigate urban heat island effects [Shi et al. (2020), p. 2, Wu et al. (2018), pp. 659–662]. Optimized design and planning methods for BGS aim to maximize these synergistic cooling effects [Du et al. (2017), pp. 9–10]. Factors such as the size, shape, spatial pattern, morphological characteristics, and landscape composition and configuration of BGS all affect the intensity of cooling that can be achieved [Cruz et al. (2021), pp. 6–10, Jiang et al. (2021), p. 6 of 29]. However, the optimal proportions and morphological characteristics of BGS to maximize its synergistic cooling effect remain uncertain and warrant further investigation.

Urban stormwater flooding, triggered by extreme rainfall, is another extreme climate phenomenon in cities. In recent years, more large cities have been affected by flood disasters due to extreme rainfall, posing serious threats to human life, natural habitat, and socioeconomic development. To mitigate the influence of urban flooding and conserve urban water resources, the co-benefits of BGS have been recognized. Additionally, there is increasing understanding of the potential of nature-based solutions and the synergistic functions of BGI [Ahmed et al. (2019), p. 7 of 21, Alves et al. (2020), pp. 11–12].

Some scholars have conducted preliminary explorations into the synergistic functions and development strategies of BGS as integrated infrastructure. They regard BGS as a nature-based solution with potential to improve urban climate adaptability and ecological resilience [JingShu (2020), pp. 7–9]. In fact, the current concept of BGI extends previous models such as low-impact development, water-sensitive urban design, and sponge-city construction [Chang et al. (2018), p. 377]. One objective of these concepts has been to enhance the structure of green spaces and water bodies to mitigate climate change and manage urban stormwater [Sorensen et al. (2021), pp. 3–5]. However, due to the involvement of multiple disciplines and interest groups, the implementation of BGI is still in its nascent stages. Our literature analysis reveals that quantitative studies and mechanistic analyses of the multiple effects and climate mitigation functions of BGS and its integration into urban infrastructure, are limited. The interactive effects of BGS/BGI on climatic extremes (e.g., urban stormwater management and urban heat island mitigation) also require further investigation.

3.4.2 Progress and deficiencies of BGS research in human health promotion

Research on promoting human health through BGS can be categorized by 34 keywords. Terms such as "physical activity," "mental health," "exposure," "health," and "benefits" appeared frequently and have strong node degrees (Fig. 7). Research in this area analyzed how the layout of BGS influences people's relative exposure to and access to blue or green space, as well as its effects on human behavior, physical health, and mental health [Labib et al. (2020), pp. 9–13]. The most commonly used research methods include social surveys and sensory perception [Fisher et al. (2021), p. 3], along with research that combines the structural characteristics of material spaces with quantitative indicators of human health [Tan et al. (2021), p. 2, Lin et al. (2021), p. 2 of 18].

Numerous studies have indicated that the fast-paced nature of city life, compounded by COVID-19 pandemic lockdowns, has reduced opportunities for residents to connect with nature. This reduction in nature contact could induce and exacerbate mental health issues [Pouso et al. (2021), p. 2]. Specific characteristics of BGS, such as the presence of natural sounds, high species richness, and abundant vegetation and water coverage, are perceived as restorative to human health, leading to improved well-being [Fisher et al. (2021), p. 2 of 13]. Exposure to BGS has both direct and indirect positive effects on human health by restoring human perception, relieving stress,

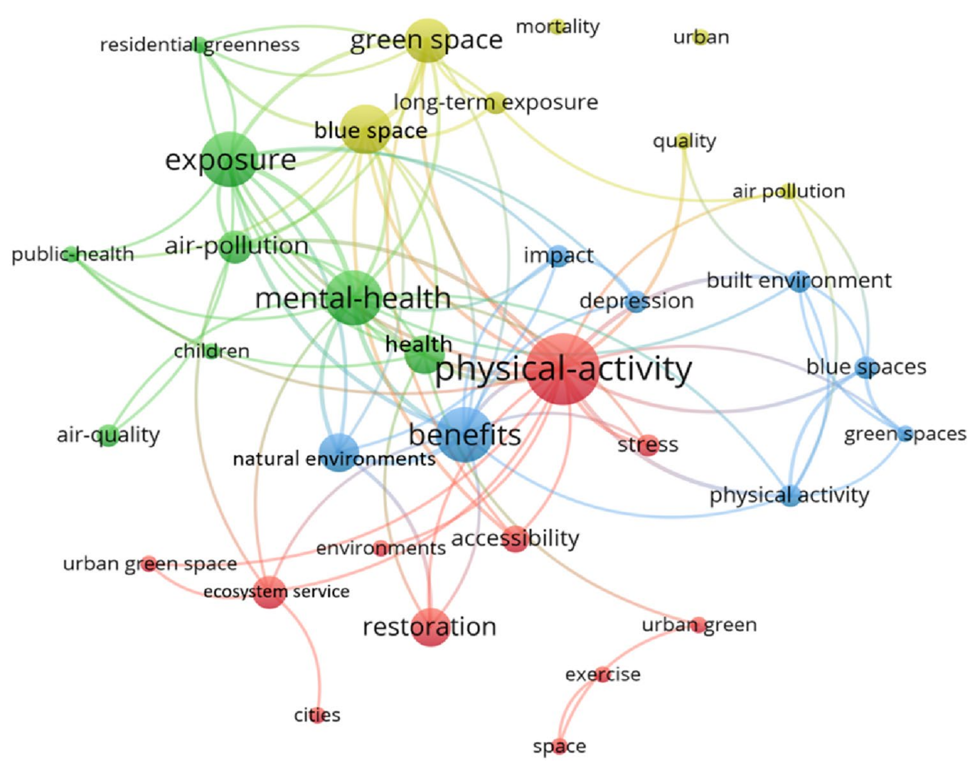

Fig. 7 Hot spot visual analysis of BGS research in promoting human health

regulating mood, and improving air quality [White et al. (2021), p. 6 of 12, Rygal et al. (2021)].

The positive effects of exposure to BGS on children's cognitive development have been verified. The benefits include the inhibition of impulsive behavior, the promotion of prosocial behavior, and the stimulation of the imagination [Heezik et al. (2021), pp. 5–7]. BGS can also play a role in health interventions and adjunctive treatments aimed at improving the quality of life for individuals with dementia [Wu et al. (2021), pp. 1607–1609], emotional disorders in adolescents, attention deficits, prosocial disorders, and attention-deficit hyperactivity disorder (ADHD) [Dzhambov et al. (2018), pp. 228–231]. Consequently, age and sex differences should be considered in the planning and design of future BGS. Further research is needed on the synergistic mechanisms and regulatory effects of BGS on human health. In particular, studies focused on optimizing BGS design to enhance human health and quality of life require more intensive investigation.

3.4.3 Progress and deficiencies of BGS research in enhancement of ecosystem services

Research on ecosystem services provided by BGS encompasses 41 keywords, with "ecosystem services" occupying the most central position. Terms such as "management," "city," "green infrastructure," "blue–green infrastructure," "nature-based solutions," and "urban" all have strong connections to "ecosystem services" (Fig. 8). Although "vegetation" and "thermal comfort" are positioned at the periphery of the knowledge network, they bridge the two different scales of "urban" and "city," and are related to "ecosystem services."

In these studies, the ecological resilience and multiple benefits of BGI have been extensively examined. The ecosystem service value of BGI in improving urban air quality and recreation [Menconi et al. (2021), p. 2], regulating temperature and stormwater [Veerkamp et al. (2021), pp. 4–6], increasing biodiversity [Nguyen et al. (2021)], achieving carbon neutrality [Guo et al. (2021), pp. 12–14], and promoting urban sustainable development [Li et al. (2017), p. S12] is increasingly recognized. Researchers and planners concur that BGI can be viewed as a comprehensive, interdependent ecosystem, and that nature-based solutions can be utilized to improve climate resilience and the provision of ecosystem services in urban areas [Langemeyer et al. (2021), pp. 7–9]. The ecosystem services provided by BGI are influenced by the extent of vegetation and water areas, as well as their proximity to city centers [Dai et al. (2021), p. 4]. However, "ecosystem services" is a broad concept encompassing ecology, social services, and human well-being. The extent to which ecosystem services can be amplified by coordinating the provision of BGI remains uncertain. Construction methods and optimal spatial arrangements for optimizing the compound effects of BGI on ecosystem services require further research and clarification.

3.4.4 Progress and deficiencies of BGS research in planning practice

Research on planning practices for BGS encompasses 38 keywords, with "green infrastructure," "infrastructure," "cities," "design," and "impact" having high node degrees (Fig. 9). Research associated with these terms addresses topics like stormwater management, climate change adaptation, land-use

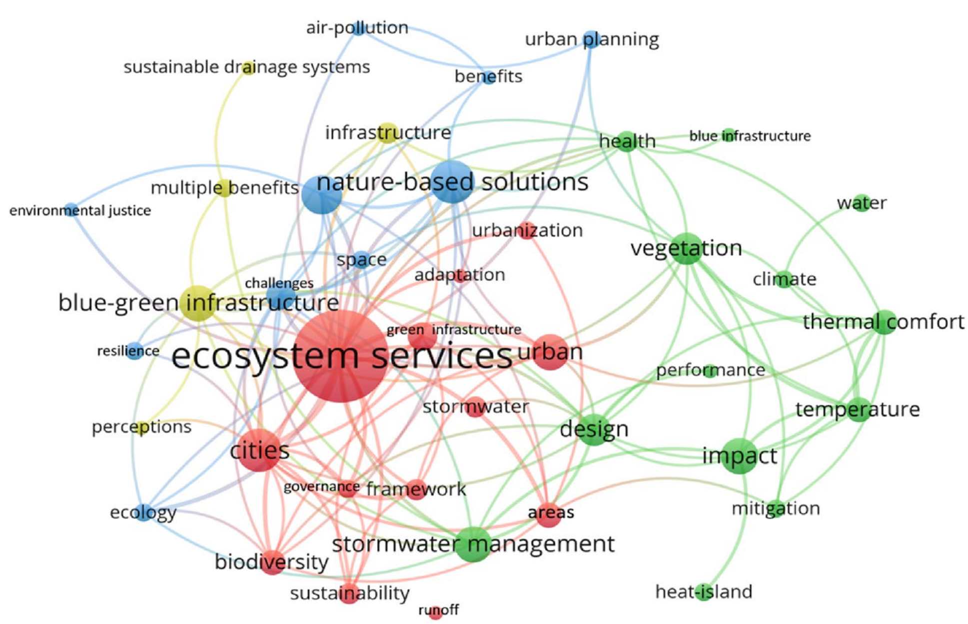

Fig. 8 Hot spot visual analysis of BGS research in enhancing ecosystem services

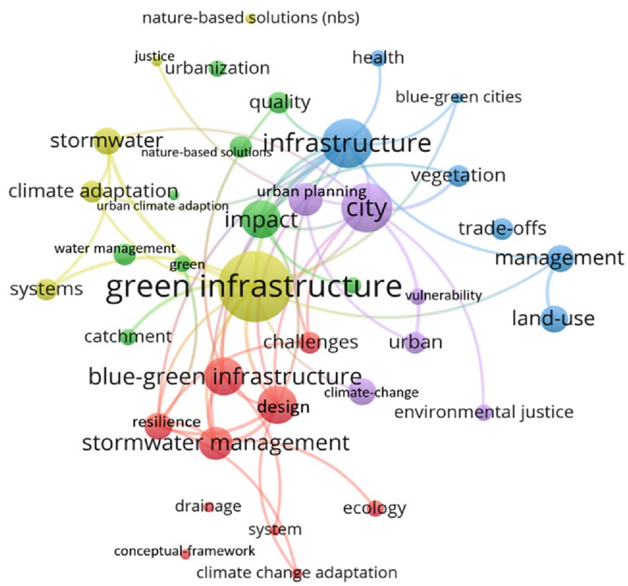

Fig. 9 Hot spot visual analysis of BGS research in spatial planning practice

management, health effects, and thermal comfort. Both domestic and international industry organizations, as well as experts and scholars, have actively explored the integrated development and collaborative planning of BGS based on its distribution and multiple functions. BGS has been recognized as a distinct category of infrastructure in urban planning practice [Zhou et al. (2020), p. 13 of 22, Sorensen et al. (2021), pp. 7–9]. The primary goals of such research include optimizing land-use structure, addressing urban flooding issues, improving urban climate adaptability, and enhancing thermal comfort in urban areas. International organizations such as the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) and the Intergovernmental Panel on Climate Change (IPCC) regard BGI as a nature-based solution for bolstering urban adaptation and resilience [Borie et al. 2021, p. 8, Macedo et al. (2021), p. 3].

Authorities in Stuttgart, Germany, and Melbourne, Australia, are striving to improve the urban climate through the construction of BGI. Seattle, USA, and Rotterdam, the Netherlands, aim to reduce surface runoff by increasing BGS. Many Chinese cities regard BGS as a crucial element in the development of sponge cities and resilient cities. Zhou et al. (2020)) developed a planning support tool for the layout and integral optimization of urban BGI [Zhou et al. (2020), pp. 4–7 of 22]. Pepe Puchol-Salort et al. (2021) introduced a system-based Urban Planning Sustainability Framework (UPSUF), which integrates sustainability evaluation, design solutions, and planning system process into a Geographical Information System. This framework's goal is to incorporate blue–green solutions into urban planning [Puchol-Salort et al. (2021), pp. 1–3]. These planning approaches aim to promote the harmonious coexistence of natural and artificial systems through BGI planning interventions, thereby creating better, healthier, and more comfortable living environment. In China, guided by the concept of ecological civilization, cities have explored the integration of BGS into city infrastructure development goals. Following the compilation of national territorial spatial planning in 2020, such integration has been widely proposed. Planning interventions include the construction of Beijing's blue–green ecological network, focusing on the integration of BGS and human–water harmonies [Lei (2012)]; the development of urban and rural BGS networks in the Pearl River Delta, guided by green urban design [Wang et al. (2021)]; and BGS planning based on thermal environment simulation in central Shanghai [Du et al. (2019), pp. 7–9].

4 Discussion

4.1 The changing process of BGS research themes

Drawing on the quantitative analysis outlined earlier, the study investigated the research themes related to BGS across various stages of its development, as summarized in Table 3. Collaborative research on BGS began to gain momentum around 2012. Prior to 2015, studies predominantly focused on the positive impacts of BGS, specifically in regulating human activities and mitigating mental stress. Between 2015 and 2017, BGS came to be recognized as a crucial ecological component and an integral part of urban infrastructure. During this period, the conceptual connotations and functions of BGS were greatly expanded. Researchers hoped to alleviate ecological problems produced by rapid urbanization in the past and to find nature-based solutions to climate change by exploring synergies functions of BGS in ecosystem services and climate regulation [Li et al. (2017), pp. 15–16]. Since 2018, emerging challenges such as extreme high temperature, intense urban rainfall and flooding, and biodiversity loss became increasingly prominent in BGS research. During this period, the focus of BGS research was to exploring the coevolution between cities and nature, and to finding systematic nature-based solutions to those challenges.

In the recent development stage (2018–2022), government managers have increasingly focused on the coordinated management of BGS, particularly in China, where collaborative planning projects on BGS have seen a notable rise. Driven by practical planning needs, researchers are progressively emphasizing BGI as a nature-based solution. They are integrating this concept with urban gray infrastructure, such as pipe networks, to improve rainwater regulation and storage capabilities [Alves et al. (2020), p. 12]. As cities come under pressure from increasingly

Table 3 Analysis of research themes and status of BGS across various development stages

Development stage	Main research themes	Development status
Early stage (2012–2014)	alleviating the effects of urban heat islands [Hathway and Sharples (2012)] reducing stormwater flows and reusing rainwater [Rozos et al. (2013)] affecting human activities [Amoly et al. (2014)]	The synergistic effects of BGS were initially recognized
Midterm stage (2015–2017)	provision of ecological services [Andersson et al. (2015), Dou et al. (2017)] improvements to human mental health and well-being [Gascon et al. (2015), Finlay et al. (2015)] climate change mitigation and adaptation [Voskamp and Ven (2015), Kabisch et al. (2016)]	The synergistic effects of BGS have increasingly garnered attention
Recent stage (2018–2022)	enhancing environmental quality [Wang (2021)] increasing urban resilience [Joyce et al. (2018)] improving human health [White et al. (2021)] enhancing urban comfort through cooling and humidification [Shi et al. (2020), Hu et al. (2020)]; regulating urban stormwater with gray infrastructure via nature-based solutions [Ncube and Arthur (2021)] providing ecosystem services such as carbon storage, biodiversity protection, cultural benefits, and human well-being [Veerkamp et al. (2021)] integrative development, collaborative planning of BGS [Puchol-Salort et al. (2021), Sorensen et al. (2021)] and investments in BGI [Pallathadka et al. (2022), Kaur et al. (2022)]	Research on the synergistic effect of BGS has shown explosive growth in quantity and expansion in scope

severe extreme weather events associated with climate change, researchers have redoubled their efforts to understand the role of BGS-related ecological services in alleviating temperatures in urban heat islands and managing urban stormwaters [Shi et al. (2020), Yang et al. (2020), p. 10]. Influenced by the sudden outbreak of new coronary pneumonia (COVID-19), the positive effects of BGS on air purification and the relief of mental stress have been re-emphasized [Pouso et al. 2020, p. 2]. The distributional fairness and accessibility of BGS to city residents have also been widely discussed [Nghiem et al. (2021), pp. 6–7, Liu et al. (2021), pp. 8–9]. The positive effect of BGS in reducing mortality rates has been affirmed [Labib et al. (2022), p. 9]. Investments in BGI are increasingly considered by urban managers and planners to address urban flood problems [Pallathadka et al. (2022), pp. 11–12, Kaur et al. (2022), p. 11]. Furthermore, the methods and strategies for integrated development, collaborative planning, and network construction of BGS are being actively explored and practiced [Puchol-Salort et al. (2021), Sorensen et al. (2021), p. 8].

As time has progressed, investigations of BGS have become more abundant, and the number of disciplines involved has diversified. Research on correlations between the structure and function of BGS has intensified, and it has produced advances that range from mechanistic understanding of the role of BGS to the analysis of its feedback regulation.

4.2 The policy-driven BGS research in China

China holds the distinction of having the highest number of publications in the field of BGS. The policy orientation and development concept of the Chinese government have been pivotal in accelerating the growth of this field. China has a deep understanding of the ecological issues associated with rapid urbanization during the past decades, and appreciates the importance of achieving healthy and sustainable urbanization through the construction of "ecological civilization" [Wu et al. (2021), Zhang et al. (2022), p. 2]. Since 2012, reports of the three congresses of the Communist Party of China (the 18th, 19th, and 20th Congresses) have emphasized the importance of constructing an ecological civilization [Zhang et al. (2016), p. 1], of achieving conservation objectives, and restoring damaged environments [Chen et al. (2023), p. 2]. A series of ecological concepts such as the "community of life" and the "harmonious coexistence of nature and mankind" have been proposed as basic requirements for the high-quality development of China's territorial space [Gao et al. (2022), p. 13]. Under the new territory spatial planning system in China, the properties, synergy, and indicator system of BGS have been explored and studied [Duo et al. (2022)]. The Chinese government even regards BGS development as a key component of planning for ecological spaces across the national territory in the new era [Ministry of Natural Resources (Ministry of Natural Resources of the People's Republic of China (2020) Guidelines for the compilation of the Municipal Land Space Master Plan. Natural Resources [2020], No. 46, p. 11 of 44 2020), p. 11 of 44]. The proportion of BGS in built-up areas is set to become a guiding index for the future creation of national garden cities [Ministry of Housing and Urban–Rural Development (Ministry of Housing and Urban-Rural Development of the People's Republic of China (2022) Notice of the Ministry of Housing and Urban-Rural Development on Printing and distributing Administrative Measures for the Application and Selection of National Garden Cities, Jiancheng [2022], No. 2, p. 15 2022), p. 15]. According to the "National Garden City Selection Criteria" of 2022, a BGS proportion greater than 45% and 43% in built-up area has been included as a key evaluation indicator for national ecological garden cities and national garden cities, respectively. This designation affirmed China's emphasis on and affirmation of the importance of BGS for analyzing the consequences of urban ecology and the need for the collaborative construction of BGS. The amendment of these selection criteria is also anticipated to be a major driving force in advancing BGS research in China.

4.3 Lacunae and opportunities in BGS planning practice

Under the influence of major events, such as the global pandemic and increasingly frequent extreme weather, the positive co-benefits derived from the BGS have been further emphasized and studied. Scholars agreed that the integration of blue and green spaces and achieving synergies between them can improve ecological resilience and the health of human settlements [Oliveira et al. (2022), pp. 7–10]. This approach to integrated development and collaborative planning of BGS has been extensively implemented in projects aimed at enhancing urban environments in various countries [Zhou and Wu (2020), pp. 1–2 of 22, Ahmed and Alam (2019)]. It is widely recognized that combining BGS multiplies the environmental benefits of each type of space. Nevertheless, there is a notable deficiency in comprehensive research on the integrated planning and collaborative construction of BGS. Furthermore, most of the current BGS planning strategies are grounded in empirical practices and theoretical frameworks. Examples of multi-scale socio-ecological practices that support such integrated planning are scarce. Socio-ecological practice is the human action and social process that take place in specific socio-ecological context to bring about a secure, harmonious, and sustainable socio-ecological condition serving human beings' need for survival, development, and flourishing [Xiang W–N (2019), P. 7]. In the current socio-ecological context of climate change mitigation and the development of high-quality human settlements, the socio-ecological practice of BGS is of great significance. Currently, a lack of scientific technical standards and unified planning guidelines exists to facilitate the planning process of BGS, highlighting an urgent need for further research and development in this domain.

5 Conclusions

The objective of this paper was to summarize and categorize the progress and hot spots in international BGS research. We utilized bibliometric methods to conduct a statistical analysis of 350 papers selected from the WOS database. The results indicate a gradual increase in BGS research publications over the past decade. China, the UK, and the USA have been the three major contributing countries in this field. Additionally, there has been an increase in the collaboration intensity between different countries in BGS research. In the last five years, Chinese institutions have become central in both research and practice within this field. The principal research hot spots in BGS are problem-oriented, focusing on climate change adaptation and mitigation, enhancing ecosystem services, promoting human health, and spatial planning practice. Current research has confirmed the synergies and composite functions of BGS. However, mechanisms to achieve synergy, collaborative planning development, and the optimization of BGS spatial patterns are still largely theoretical. Therefore, we conclude that further exploration is needed in quantitative research and socio-ecological practice to support BGS development. A critical issue for the sustainable development of human settlements is how to optimize the layout of BGS in terms of form and quantity to maximize its benefits. This question deserves further investigation.

Acknowledgements We sincerely thank Editors and the anonymous reviewers for comments which improved our manuscript.

Author contribution BM was the project and overall research manager and wrote the manuscript; RZ was the data processing analyst and wrote the manuscript; YL was the language editor and wrote the manuscript; EX and YZ was the co-investigator and wrote the manuscript; and HW and GT were the overall research manager and wrote the manuscript.

Funding This study was funded by the National Natural Science Foundation of China (51808198), and the Science and Technology Department of Henan Province (the special project of Key Research and Promotion of Henan Province 222400410323 and the High-level Foreign Expert Import Program of Henan Province HNGD2022042).

Declarations

Conflict of interest The authors declare that they have no conflict of interests.

References

Ahmed S, Meenar M, Alam A (2019) Designing a blue–green infrastructure (BGI) network: toward water-sensitive urban growth planning in Dhaka. Bangladesh Land 8:138. https://doi.org/10.3390/land8090138

Alves A, Vojinovic Z, Kapelan Z et al (2020) Exploring trade-offs among the multiple benefits of green–blue–grey infrastructure for urban flood mitigation. Sci Total Environ 703:134980. https://doi.org/10.1016/j.scitotenv.2019.134980

Amoly E, Dadvand P, Forns J et al (2014) Green and blue spaces and behavioral development in Barcelona schoolchildren: the BREATHE project. Environ Health Perspect 122:1351–1358. https://doi.org/10.1289/ehp.1408215

Andersson E, Tengö M, McPhearson T et al (2015) Cultural ecosystem services as a gateway for improving urban sustainability. Ecosyst Serv 12:165–168. https://doi.org/10.1016/j.ecoser.2014.08.002

Borie M, Mahony M, Obermeister N et al (2021) Knowing like a global expert organization: comparative insights from the IPCC and IPBES. Glob Environ Chang 68:102261. https://doi.org/10.1016/j.gloenvcha.2021.102261

Chang NB, Lu JW, Chui TFM et al (2018) Global policy analysis of low impact development for stormwater management in urban regions. Land Use Policy 70:368–383. https://doi.org/10.1016/j.landusepol.2017.11.024

Chen X, Kang B, Li M et al (2023) Identification of priority areas for territorial ecological conservation and restoration based on ecological networks: a case study of Tianjin City. China Ecol Indicators 146:109809. https://doi.org/10.1016/j.ecolind.2022.109809

Cruz JA, Blanco AC, Garcia JJ et al (2021) Evaluation of the cooling effect of green and blue spaces on urban microclimate through numerical simulation: a case study of Iloilo River Esplanade. Philipp Sustain Cities Soc 74:103184. https://doi.org/10.1016/j.scs.2021.103184

Dai X, Wang L, Tao M et al (2021) Assessing the ecological balance between supply and demand of blue–green infrastructure. J Environ Manag 288:112454. https://doi.org/10.1016/j.jenvman.2021.112454

Donati GFA, Bolliger J, Psomas A et al (2022) Reconciling cities with nature: identifying local blue–green infrastructure interventions for regional biodiversity enhancement. J Environ Manag 316:115254. https://doi.org/10.1016/j.jenvman.2022.115254

Donthu N, Kumar S, Mukherjee D et al (2021) How to conduct a bibliometric analysis: an overview and guidelines. J Bus Res 133:285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Dou Y, Zhen L, Groot RD et al (2017) Assessing the importance of cultural ecosystem services in urban areas of Beijing municipality. Ecosyst Serv 24:79–90. https://doi.org/10.1016/j.ecoser.2017.02.011

Du Z, Lin B (2023) Green space settlement landscape optimization strategy under the concept of ecological environment restoration. J King Saud Univ Sci 35:102539. https://doi.org/10.1016/j.jksus.2023.102539

Du H, Cai Y, Zhou F et al (2019) Urban blue–green space planning based on thermal environment simulation: a case study of Shanghai. China Ecol Indicators 106:105501. https://doi.org/10.1016/j.ecolind.2019.105501

Duo H, Fangrong Y, Sizhe W et al (2022) Blue–green space pattern and indicator system in territorial planning. City Plan Rev 46:18–31

Dushkova D, Ignatieva M, Hughes M et al (2021) Human dimensions of urban blue and green infrastructure during a pandemic case study of Moscow (Russia) and Perth (Australia). Sustainability 13:4148. https://doi.org/10.3390/su13084148

Dzhambov AM, Markevych I, Hartig T et al (2018) Multiple pathways link urban green- and blue space to mental health in young adults. Environ Res 166:223–233. https://doi.org/10.1016/j.envres.2018.06.004

Eck NJV, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84:523–538. https://doi.org/10.1007/s11192-009-0146-3

Fan Z, Zhan Q, Liu H et al (2022) Investigating the interactive and heterogeneous effects of green and blue space on urban PM2.5 concentration, a case study of Wuhan. J Clean Prod 378:134389. https://doi.org/10.1016/j.jclepro.2022.134389

Finlay J, Franke T, McKay H et al (2015) Therapeutic landscapes and wellbeing in later life: impacts of blue and green spaces for older adults. Health Place 34:97–106. https://doi.org/10.1016/j.healthplace.2015.05.001

Fisher JC, Irvine KN, Bicknell JE et al (2021) Perceived biodiversity, sound, naturalness and safety enhance the restorative quality and wellbeing benefits of green and blue space in a neotropical city. Sci Total Environ 755:143095. https://doi.org/10.1016/j.scitotenv.2020.143095

Gao M, Hu Y, Bai Y (2022) Construction of ecological security pattern in national land space from the perspective of the community of life in mountain, water, forest, field, lake and grass: a case study in Guangxi Hechi. China Ecol Indicators 139:108867. https://doi.org/10.1016/j.ecolind.2022.108867

Gascon M, Triguero-Mas M, Martínez D et al (2015) Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. Int J Environ Res Public Health 12:4354–4379. https://doi.org/10.3390/ijerph120404354

Gu Y, Lin N, Ye X et al (2022) Assessing the impacts of human disturbance on ecosystem services under multiple scenarios in karst areas of China: insight from ecological conservation red lines effectiveness. Ecol Ind 142:109202. https://doi.org/10.1016/j.ecolind.2022.109202

Gunawardena KR, Wells MJ, Kershaw T (2017) Utilising green and bluespace to mitigate urban heat island intensity. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2017.01.158

Guo H, Yu Q, Pei Y et al (2021) Optimization of landscape spatial structure aiming at achieving carbon neutrality in desert and mining areas. J Clean Prod 322:129156. https://doi.org/10.1016/j.jclepro.2021.129156

Hathway EA, Sharples S (2012) The interaction of rivers and urban form in mitigating the urban heat Island effect: a UK case study. Build Environ 58:14–22. https://doi.org/10.1016/j.buildenv.2012.06.013

Heezik Y, Freeman C, Falloon A et al (2021) Relationships between childhood experience of nature and green/blue space use, landscape preferences, connection with nature and pro-environmental behavior. Landsc Urban Plan 213:104135. https://doi.org/10.1016/j.landurbplan.2021.104135

Hong W, Guo R, Li X et al (2022) Measuring urban ecological network resilience: a disturbance scenario simulation method. Cities 131:104057. https://doi.org/10.1016/j.cities.2022.104057

Howe PD (2021) Extreme weather experience and climate change opinion. Curr Opin Behav Sci 42:127–131. https://doi.org/10.1016/j.cobeha.2021.05.005

Hu L, Li Q (2020) Greenspace, bluespace, and their interactive influence on urban thermal environments. Environ Res Lett 15:034041. https://doi.org/10.1088/1748-9326/ab6c30

Jiang Y, Huang J, Shi T et al (2021) Interaction of urban rivers and green space morphology to mitigate the urban heat Island effect: case-based comparative analysis. Int J Environ Res Public Health 18:11404. https://doi.org/10.3390/ijerph182111404

Jingshu C (2020) Spatial planning strategies of blue and green river space integration from urban resilience viewpoint. Planners 36:5–10

Joyce J, Chang NB, Harji R et al (2018) Coupling infrastructure resilience and flood risk assessment via copulas analyses for a coastal green–grey–blue drainage system under extreme weather events. Environ Model Softw 100:82–103. https://doi.org/10.1016/j.envsoft.2017.11.008

Kabisch N, Frantzeskaki N, Pauleit S et al (2016) Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecol Soc 21:39. https://doi.org/10.5751/ES-08373-210239

Kaur R, Gupta K (2022) Blue–Green Infrastructure (BGI) network in urban areas for sustainable storm water management: a geospatial approach. City Environ Interact 16:100087. https://doi.org/10.1016/j.cacint.2022.100087

Kuo PH, Shih SS, Otte ML (2021) Restoration recommendations for mitigating habitat fragmentation of a river corridor. J Environ Manag 296:113197. https://doi.org/10.1016/j.jenvman.2021.113197

Labib SM, Lindley S, Huck JJ (2020) Spatial dimensions of the influence of urban green–blue spaces on human health: a systematic review. Environ Res 180:108869. https://doi.org/10.1016/j.envres.2019.108869

Labib SM, Browning MHEM, Rigolon A et al (2022) Nature's contributions in coping with a pandemic in the 21st century: a narrative review of evidence during COVID-19. Sci Total Environ 833:155095. https://doi.org/10.1016/j.scitotenv.2022.155095

Lamond J, Everett G (2019) Sustainable blue–green infrastructure: a social practice approach to understanding community preferences and stewardship. Landsc Urb Plan 191:103639

Langemeyer J, Baró F (2021) Nature-based solutions as nodes of green–blue infrastructure networks: a cross-scale, co-creation approach. Nat Solut 1:100006. https://doi.org/10.1016/j.nbsj.2021.100006

Lei Y (2012) Integration of water and green, coincides with water and green: building ecological networks of the combination of "blue and green". In: 2012 International federation of landscape architects (IFLA) Asia pacific conference and China society of landscape architecture, Meng Z (ed.), China building industry press: Shanghai city, China. pp. 303-306

Li F, Liu X, Zhang X et al (2017) Urban ecological infrastructure: an integrated network for ecosystem services and sustainable urban systems. J Clean Prod 163:S12–S18. https://doi.org/10.1016/j.jclepro.2016.02.079

Li X, Chen WY, Hu FZY et al (2021) Homebuyers' heterogeneous preferences for urban green–blue spaces: a spatial multilevel autoregressive analysis. Landsc Urb Plan 216:104250. https://doi.org/10.1016/j.landurbplan.2021.104250

Li Y, Li M, Sang P (2022) A bibliometric review of studies on construction and demolition waste management by using cite space. Energy Build 258:111822. https://doi.org/10.1016/j.enbuild.2021.111822

Lin C, Wu L (2021) Green and blue space availability and self-rated health among seniors in China: evidence from a national survey. Int J Environ Res Public Health 18:545. https://doi.org/10.3390/ijerph1802045

Liu D, Kwan MP, Kan Z (2021) Analysis of urban green space accessibility and distribution inequity in the City of Chicago. Urb for Urb Green 59:127029. https://doi.org/10.1016/j.ufug.2021.127029

Liu H, Peng D, Yang HJ, Mu Y, Zhu Y (2023) Exploring the evolution of sustainable fisheries development: focusing on ecological, environmental and management issues. Ecol Inform 75:102004. https://doi.org/10.1016/j.ecoinf.2023.102004

Lv L, Pol MD, Osmond H et al (2023) Winter mortality of a passerine bird increases following hotter summers and during winters with higher maximum temperatures. Sci Adv. https://doi.org/10.1126/sciadv.abm0197

Macedo LSVd, Picavet ME, Oliveira JAD et al (2021) Urban green and blue infrastructure: a critical analysis of research on developing countries. J Clean Prod 313:127898. https://doi.org/10.1016/j.jclepro.2021.127898

Menconi ME, Palazzoni L, Grohmann D (2021) Core themes for an urban green systems thinker: a review of complexity management in provisioning cultural ecosystem services. Urb for Urb Green 65:127355. https://doi.org/10.1016/j.ufug.2021.127355

Ministry of housing and urban–rural development of the people's republic of China (2022) Notice of the ministry of housing and urban–rural development on printing and distributing administrative measures for the application and selection of national garden cities, Jiancheng [2022], No.2, P.15

Ministry of natural resources of the people's republic of China (2020) Guidelines for the compilation of the Municipal land space master plan. Natural Resources [2020] No. 46, p. 11 of 44

Namkhan M, Sukumal N, Savini T (2022) Impact of climate change on Southeast Asian natural habitats, with focus on protected areas. Glob Ecol Conserv 39:e02293. https://doi.org/10.1016/j.gecco.2022.e02293

Ncube S, Arthur S (2021) Influence of blue–green and grey infrastructure combinations on natural and human-derived capital in urban drainage planning. Sustainability 13:2571. https://doi.org/10.3390/su13052571

Nghiem LTP, Zhang Y, Oh RRY et al (2021) Equity in green and blue spaces availability in Singapore. Landsc Urban Plan 210:104083. https://doi.org/10.1016/j.landurbplan.2021.104083

Nguyen TT, Meurk C, Benavidez R et al (2021) The effect of blue–green infrastructure on habitat connectivity and biodiversity: a case study in the ¯Ot¯akaro/Avon river catchment in Christchurch. NZ Sustain 13:6732. https://doi.org/10.3390/su13126732

Oliveira JAPd, Bellezoni RA, Shih W et al (2022) Innovations in urban green and blue infrastructure: tackling local and global challenges in cities. J Clean Prod 362:132355. https://doi.org/10.1016/j.jclepro.2022.132355

Pallathadka A, Sauer J, Chang H et al (2022) Urban flood risk and green infrastructure: Who is exposed to risk and who benefits from investment? A case study of three US cities. Landsc Urb Plan 223:104417. https://doi.org/10.1016/j.landurbplan.2022.104417

Pouso S, Borja Á, Fleming LE et al (2021) Contact with blue–green spaces during the COVID-19 pandemic lockdown beneficial for mental health. Sci Total Environ 756:143984. https://doi.org/10.1016/j.scitotenv.2020.143984

Puchol-Salort P, O'Keeffe J, Reeuwijk M et al (2021) An urban planning sustainability framework: systems approach to blue green urban design. Sustain Cities Soc 66:102677. https://doi.org/10.1016/j.scs.2020.102677

Rozos E, Makropoulos C, Maksimovic C (2013) Rethinking urban areas: an example of an integrated blue–green approach. Water Sci Technol 13:1534–1542. https://doi.org/10.2166/ws.2013.140

Rygal N, Swami V (2021) Simulated nature and positive body image: a comparison of the impact of exposure to images of blue and green spaces. Body Image 39:151–155. https://doi.org/10.1016/j.bodyim.2021.08.004

Sanchez FG, Govindarajulu D (2023) Integrating blue–green infrastructure in urban planning for climate adaptation: lessons from Chennai and Kochi India. Land Use Policy 124:106455. https://doi.org/10.1016/j.landusepol.2022.106455

Sander HA, Zhao C (2015) Urban green and blue: who values what and where? Land Use Policy 42:194–209. https://doi.org/10.1016/j.landusepol.2014.07.021

Shen Z, Ji W, Yu S et al (2023) Mapping the knowledge of traffic collision reconstruction: a scientometric analysis in CiteSpace, VOSviewer, and SciMAT. Sci Justice 63:19–37. https://doi.org/10.1016/j.scijus.2022.10.005

Shi D, Song J, Huang J et al (2020) Synergistic cooling effects (SCEs) of urban green–blue spaces on local thermal environment: a case study in Chongqing China. Sustain Cities Soc 55:102065. https://doi.org/10.1016/j.scs.2020.102065

Sorensen J, Persson AS, Olsson JA (2021) A data management framework for strategic urban planning using blue–green infrastructure. J Environ Manag 299:113658. https://doi.org/10.1016/j.jenvman.2021.113658

Sun Z, Behrens P, Tukker A et al (2022) Shared and environmentally just responsibility for global biodiversity loss. Ecol Econ 194:107339. https://doi.org/10.1016/j.ecolecon.2022.107339

Tamala JK, Maramag EI, Simeon KA et al (2022) A bibliometric analysis of sustainable oil and gas production research using VOSviewer. Clean Eng Technol 7:100437. https://doi.org/10.1016/j.clet.2022.100437

Tan CLY, Chang CC, Nghiem LTP et al (2021) The right mix: residential urban green–blue space combinations are correlated with physical exercise in a tropical city-state. Urb for Urb Green 57:126947. https://doi.org/10.1016/j.ufug.2020.126947

Veerkamp CJ, Schipper AM, Hedlund K et al (2021) A review of studies assessing ecosystem services provided by urban green and blue infrastructure. Ecosyst Serv 52:101367. https://doi.org/10.1016/j.ecoser.2021.101367

Voskamp IM, Ven FHMVd (2015) Planning support system for climate adaptation: composing effective sets of blue–green measures to reduce urban vulnerability to extreme weather events. Build Environ 83:159–167. https://doi.org/10.1016/j.buildenv.2014.07.018

Wang ZH (2021) Compound environmental impact of urban mitigation strategies: co-benefits, trade-offs, and unintended consequence. Sustain Cities Soc 75:103284. https://doi.org/10.1016/j.scs.2021.103284

Wang S, Liu L (2021) From corridor to whole region: construction of urban and rural blue–green space network under the guidance of green urban design. Landsc Archit 28:45–50. https://doi.org/10.04185/j.fjyl.2021.08.0045.06

Wei X, Liu Q, Pu A et al (2022) Knowledge mapping of bioeconomy: a bibliometric analysis. J Clean Prod 373:133824. https://doi.org/10.1016/j.jclepro.2022.133824

White MP, Elliott LR, Grellier J et al (2021) Associations between green/blue spaces and mental health across 18 countries. Sci Rep 11:8903. https://doi.org/10.1038/s41598-021-87675-0

Wolch JR, Byrne J, Newell JP (2014) Urban green space, public health, and environmental justice: the challenge of making cities 'just green enough.' Landsc Urb Plan 125:234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Wu D, Wang Y, Fan C et al (2018) Thermal environment effects and interactions of reservoirs and forests as urban blue–green infrastructures. Ecol Indicators 91:657–663. https://doi.org/10.1016/j.ecolind.2018.04.054

Wu M, Liu Y, Xu Z et al (2021) Spatio-temporal dynamics of China's ecological civilization progress after implementing national conservation strategy. J Clean Prod 285:124886. https://doi.org/10.1016/j.jclepro.2020.124886

Wu YT, Clare L, Jones IR et al (2021b) Perceived and objective availability of green and blue spaces and quality of life in people with dementia: results from the IDEAL programme. Soc Psychiatry Psychiatr Epidemiol 56:1601–1610. https://doi.org/10.1007/s00127-021-02030-y

Xiang W-N (2019) Ecopracticology: the study of socio-ecological practice. Socio Ecol Pract Res 1:7–14. https://doi.org/10.1007/s42532-019-00006-6

Xue X, He T, Xu L et al (2022) Quantifying the spatial pattern of urban heat islands and the associated cooling effect of blue–green landscapes using multisource remote sensing data. Sci Total Environ 843:156829. https://doi.org/10.1016/j.scitotenv.2022.156829

Yang G, Yu Z, Jørgensen G et al (2020) How can urban blue–green space be planned for climate adaption in highlatitude cities? A seasonal perspective. Sustain Cities Soc 53:101932. https://doi.org/10.1016/j.scs.2019.101932

Yu Z, Yang G, Zuo S et al (2020) Critical review on the cooling effect of urban blue–green space: a threshold-size perspective. Urb for Urb Green 49:126630. https://doi.org/10.1016/j.ufug.2020.126630

Yuan L, Liu D, Tian B et al (2022) A solution for restoration of critical wetlands and waterbird habitats in coastal deltaic systems. J Environ Manage 302:113996. https://doi.org/10.1016/j.jenvman.2021.113996

Zhang B, Xie G, Gao J et al (2014) The cooling effect of urban green spaces as a contribution to energy-saving and emission-reduction: a case study in Beijing, China. Build Environ 76:37–43. https://doi.org/10.1016/j.buildenv.2014.03.003

Zhang X, Wang Y, Qi Y et al (2016) Evaluating the trends of China's ecological civilization construction using a novel indicator system. J Clean Prod 133:910–923. https://doi.org/10.1016/j.jclepro.2016.06.202

Zhang L, Wang H, Zhang W et al (2022) Study on the development patterns of ecological civilization construction in China: an empirical analysis of 324 prefectural cities. J Clean Prod 367:132975. https://doi.org/10.1016/j.jclepro.2022.132975

Zhao Y, Li J, Tao C et al (2022) Research hotspots and trends of cardiopulmonary exercise test: visualization analysis based on citespace. Med Nov Technol Devices 16:100191. https://doi.org/10.1016/j.medntd.2022.100191

Zhou C, Wu Y (2020) A planning support tool for layout integral optimization of urban blue–green infrastructure. Sustainability 12:1613. https://doi.org/10.3390/su12041613

Zhou Y, Yang L, Yu J et al (2022) Do seasons matter? Exploring the dynamic link between blue–green space and mental restoration. Urb for Urb Green 73:127612. https://doi.org/10.1016/j.ufug.2022.127612

Zhou W, Cao W, Wu T et al (2023) The win-win interaction between integrated blue and green space on urban cooling. Sci Total Environ 863:160712. https://doi.org/10.1016/j.scitotenv.2022.160712

Bo Mu is an associate professor and postgraduate supervisor of Land Resources Management and Landscape Architecture in the College of Resource and Environment at Henan Agricultural University at Zhengzhou, China. She focuses on the research fields of blue–green space structure optimization and function enhancement, territorial space evolution game, and planning policy.

Yali Zhang is a professor and doctoral supervisor of Land Resources Management in the College of Resources and Environment at Henan Agricultural University at Zhengzhou, China. Her research interests in urban–rural planning and qualitative evaluation of human settlements.

Ruting Zhao is a postgraduate of Land Resources Management in the College of Resources and Environment at Henan Agricultural University at Zhengzhou, China. She focuses on the investigation of synergistic effects and pattern optimization of blue–green space.

Hong Wei is an associate professor and postgraduate supervisor of Urban–rural Planning in the College of Landscape Architecture and Art at Henan Agricultural University at Zhengzhou, China. She focuses on the research fields of cultural landscapes, urban and rural historical heritage protection, and urban renewal.

Yang Liu is an assistant professor and postgraduate supervisor of Landscape Architecture in the College of Landscape Architecture and Art at Henan Agricultural University at Zhengzhou, China. His research interests in digital landscape and parametric design, landscape management, and maintenance.

Guohang Tian is a professor and doctoral supervisor of Landscape Architecture in the College of Landscape Architecture and Art at Henan Agricultural University at Zhengzhou, China. He focuses on the research fields of urban–rural green infrastructure construction practice and management, landscape planning, and design.

Enkai Xu is a lecturer and postgraduate supervisor in the College of Landscape Architecture and Art at Henan Agricultural University at Zhengzhou, China. He focuses on the research fields of landscape planning and ecological restoration, urban biodiversity conservation, and planning practice.