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Review article

Green roof development knowledge map: A review of visual analysis using CiteSpace and VOSviewer

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A R T I C L E I N F O

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A B S T R A C T

Green roofs are generally acknowledged as environmentally sustainable roof systems with several environmental, economic, and social benefits, as well as an effective and practical strategy for mitigating the negative consequences of urbanization. In this paper, we used CiteSpace and VOSviewer bibliometric software for visual analysis, citation analysis, co-authorship network, co-citation analysis, and keyword analysis for descriptive statistics on 3986 articles on "green roofs" published in the Web of Science core database since 2000. Descriptive statistics were used for citation analysis, co-authorship network, co-citation analysis, and keyword analysis. According to a review of green roofing-related research literature, (1) Through analysis from three dimensions of country, institution, and author, it was found that China, the United States, and Italy ranked among the top three countries in terms of green roof publication volume; All but three of the top 10 institutions in terms of publications are from China and all are from developed countries; A large-scale collaborative network has not yet formed among authors. (2) Through keyword clustering analysis, it was found that "green roof," "performance," and "UHI" were the three keywords with the highest frequency. The research direction of this theme mainly includes five primary themes: rainwater management, urban biodiversity, building energy efficiency, alleviating urban heat islands and improving air quality, sustainable development, and public health. Through keyword hot words, it is found that the frequency of occurrence is relatively high, mainly involving energy conservation, alleviating urban heat islands, biodiversity, and sustainable development. The research on sustainable development, its impact on urban microclimate, and air quality remains a hot topic through keyword highlighting. (3) Co-citation analysis was used to identify the most influential journals, highly cited publications, and authors. (4) Three potential study objectives have been identified: synergistic development with other green infrastructures from an urban planning standpoint, localized research on green roofs, and photovoltaic green roofs.

1. Introduction

The increasing rate of urbanization has replaced vegetated urban spaces with artificial habitats, causing a slew of issues such as

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urban heat islands, noise, air pollution, urban flooding, and biodiversity loss. Green roofs are an essential approach for improving building energy performance and sustainability by converting impermeable parts of the roof into multifunctional spaces [1,2]. Green roofs, commonly referred to as "eco-roofs," "living roofs," or "roof gardens," are building roofs that are covered with vegetation and growth media to some extent [3]. Three categories of green roofs are often used: dense, semi-dense, and huge green roofs [1]. Green roofs are commonly thought to be advantageous in terms of water storage, precipitation, and flood mitigation potential [4–6], improving urban biodiversity [7,8], building energy efficiency [9,10], mitigating urban heat island effect [11,12], reducing air pollution [13,14], and public health [15,16].

The literature review can enable researchers to quickly and effectively understand the research field. The current research status and development trends in this field can be clarified by systematically reviewing existing literature. However, most existing literature on green roofs only focuses on one aspect and lacks a comprehensive and systematic quantitative summary and review. Most studies mainly focus on narrative summary, lacking visual, intuitive expression, and overall visual bibliometric analysis is still very rare. CiteSpace and Vosviewer, on the other hand, are widely used in scientific metrology through visual citation analysis. The main objective of this study is to describe in detail the results of the existing studies and to analyze the visual knowledge map of the relevant articles in the WOS core collection database using CiteSpace, Vosviewer, and bibliometric visualization software to present the research trends related to green roofs in a clear and introductory way to promote the development of green roofs. This study aims to provide a detailed understanding of the trends in the development of green roofs, to facilitate the development of green roof research better, and to help those in the study quickly access research trends and information to provide theoretical and practical guidance for future research. The specific goals are: (1) It is important to understand which countries have conducted the best research, which institutions have made outstanding contributions, and which authors are leading figures in the field. (2) Through keyword and cluster analysis, identify specific areas in which green roofs have contributed, as well as research trends related to green roofs, to better promote the development of green roofs. (3) Through co-citation analysis, identify highly cited literature, journals, and authors in green roofs. (4) Determine possible future research directions for green roofs through the above discussion. The above goals will provide references for the theoretical and practical research of future green roofs.

2. Methods of research and data sources

We chose publications from the Web of Science core dataset as our data source because the publications from the WoS core dataset have higher quality and reputation and are highly recognized globally. Core dataset data can make our research results more convincing, universal, and representative. The subject search in Web of Science used the search equation TS = ("green roof"). The raw data generated was further filtered using "document type = paper, conference proceedings paper, review paper." In order to have a more comprehensive understanding of the development of roof greening, we found that the core journal first included in the Web of Science was in 2000. Therefore, we determined the research time of the paper from January 1st, 2000, to March 17th, 2023, and obtained 3986 data for bibliometric analysis.

Data analysis, scientific measurement, information analysis, and scientific mapping were utilized in this paper to depict and evaluate the knowledge mapping of the green roofing industry to explore its evolutionary characteristics and hot concerns. Bibliometric methods and mapped knowledge domains (MKD) have become important tools for analysis and investigation in a variety of scientific fields around the world due to the benefits of comprehensive quantitative statistics, visual information presentation, tracking the frontiers of science and technology, indicating the direction of scientific research, and objective description and evaluation [17,18]. CiteSpace and VOSviewer are the most commonly referenced tools in the bibliometric area since they are freely available, offer good analysis and visualization capabilities, and have a larger dispersion and influence [19,20]. VOSviewer is a software tool Van Eck and Waltman created at Leiden University in the Netherlands. It allows networking based on keywords, institutions, authors,

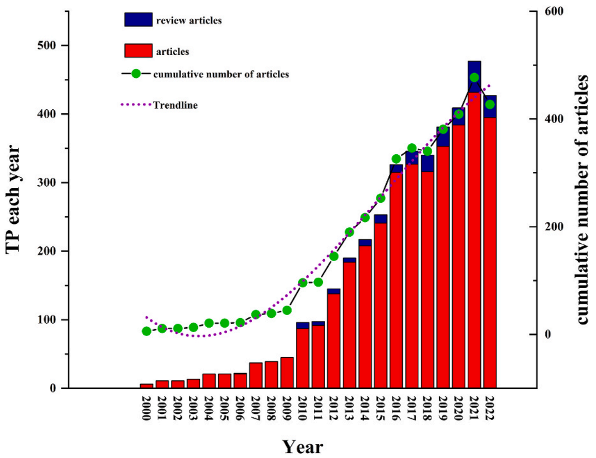

Fig. 1. The number of documents from 2000 to 2022.

publications, and so on to do co-citation analysis and show their relationships [21]. CiteSpace employs a keyword analysis tool to map scientific information and examine research topics, hotspots, and trends in specific knowledge domains [22,23]. Bibliometric is an open-source and free application for detailed scientific mapping analyses of scientific publications [24]. The bibliometric analysis of green roofing research was performed using the CiteSpace, VOSviewer, and bibliometric software packages. Therefore, we chose to use CiteSpace and Vosviewer for bibliometric analysis. It is possible to analyze the number of published articles, publishing institutions, literature sources, core author groups, research hotspots, and future trends by leveraging its advantages. At the same time, its results are visualized, making it easy to identify features and domain structures, facilitating readers' understanding and analysis, and helping to describe the distribution of hotspots in green roof research for overall and comprehensive quantitative analysis.

3. Data analysis

3.1. Annual trends in overall publication volume

The annual trend in the number of papers published objectively represents the degree of attention of academics and professionals and is an essential indicator of the current state of research, which may assist in understanding a field's growth process [17,25]. Fig. 1 displays the number of green roofing papers by time distribution. 3986 documents were retrieved, including 240 review articles (6.021 %) and 3746 publications (93.979 %). It should be noted that since the data collection ended on March 17, 2023, the data for 2023 are incomplete, and the data for 2023 are not included in the generation of discounted, bar, and trend charts; also, since the data of web of science are updated in real-time, the number of articles obtained under the same search conditions may be different.

To forecast future publishing patterns, a polynomial was fitted to the number of publications in Origin to provide a fitted curve (dashed line in Fig. 1). The trend equation is $y = -0.08018x^3 + 484.72925x^2 - 976761.70614x + 6.56058E8$. The number of publications is represented by y in the equation, while the publication year I.D. is represented by x in chronological sequence. In this equation, the model fit curve shows a positive trend in the number of annual publications over the previous 20 years ($R^2 = 0.98496$; the closer R^2 is to 1, the better the trend line fit). The number of publications will continue to climb, according to the trend line.

The publication years may be separated into two periods based on the number of publications: 2000 to 2011 and 2012. According to Fig. 1, there were more papers in the field from 2000 to 2011 than in the previous year, although the growth rate was only marginally faster. 2012 there were 138 publications, going beyond 100 for the first time. The number of studies published has dramatically grown between 2012 and 2022, demonstrating that academics are becoming more aware of the potentials of green roofing.

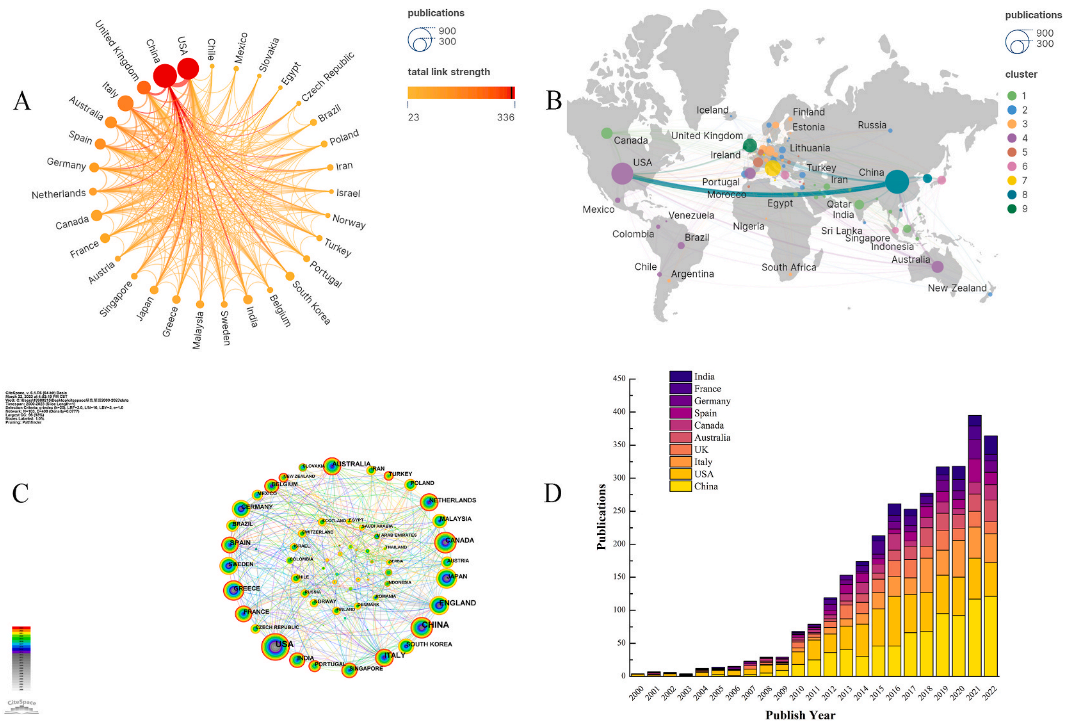

Fig. 2. Scientific production and cooperation relations among countries.

3.2. Analysis and cooperation on the main research forces of green roofs

3.2.1. Analysis of the cooperation network of countries

To evaluate a country's contribution in green roofs, the country/region cooperation network generated through VOSviewer was imported into Scimago Graphica to generate radiation maps and publish the distribution of countries. The detailed information is shown in Fig. 2A and B. The size of the nodes in Fig. 2A is proportional to the number of articles, and they indicate the number of national publications. The node color represents the level of country collaboration; the degree of international collaboration increases as the node gets closer to red. The link size in Fig. 2B represents the weight of the country's papers, and the breadth shows the level of collaboration between the two nations. CiteSpace's country collaboration network is depicted in Fig. 2C, with 3986 papers published in 103 countries or regions. The country collaboration network can reveal the distribution of research power in green roofing, with strong research capacity in countries with high activity. Nodes with high centrality have purple outer rings, and the centrality of nodes is a graph theory property that is the primary measure of node significance. The size of node fonts and labels positively correlates with the number of articles published in a nation or area.

The core nodes are the UK, France, Spain, Italy, Germany, USA, Canada, Singapore, and Malaysia (centrality >0.1), denoted by purple circles. In the field of green roofs, most publications came from five countries - China (837/3986, 21.00%), the United States (697/3986, 17.49%), Italy (375/3986, 9.41%), the United Kingdom (253/3986, 6.35%) and Australia (213/3986, 5.34%) - which published 59.58% (2375/3986) of the total number of articles. Among the top 10 countries, the United States, Italy, the United Kingdom, Canada, Spain, Germany, and France show a high degree of centrality. Fig. 2D depicts the number of papers published in the top ten nations over a year.

3.2.2. Institutional analysis

In VOSviewer, the minimum amount of articles published by institutions is set to 10, and 14 clusters of 124 institutions are obtained to fulfill the threshold value. Each node in Fig. 3A represents an institution, the size denotes the number of published papers, and the color symbolizes the same cluster. The thickness of the connecting line represents the degree of collaboration between the two institutions. The top five with the highest total link strength are Chinese Academy of Sciences (53), Arizona State University (40), National University of Singapore (35), Tsinghua University (28), Hong Kong University of Science and Technology (23), and Delft

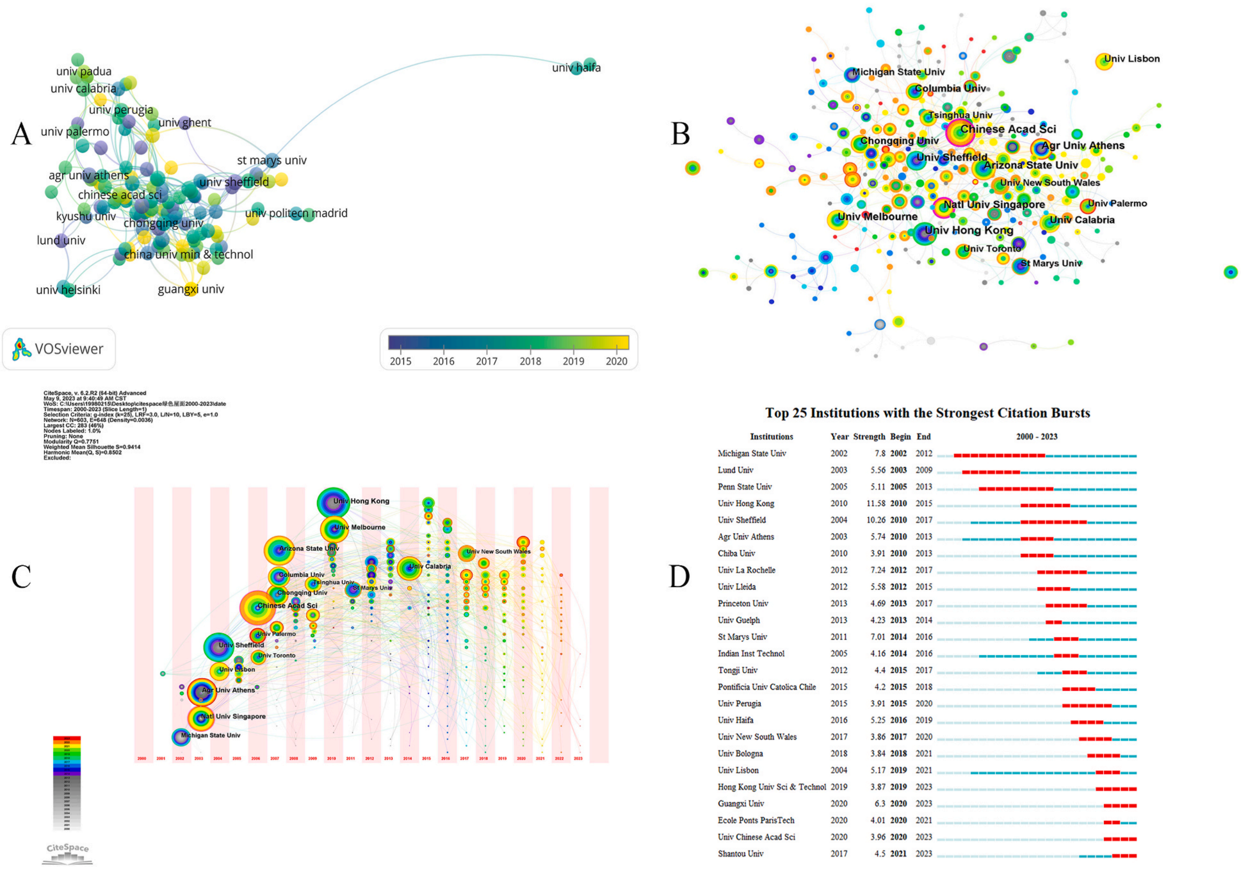

Fig. 3. Institutional collaboration.

University of Technology (22). A higher total linkage intensity indicates higher cooperation and connection between national institutions. The biggest linked cluster comprises 22 universities, including the National University of Singapore, the University of Perugia, and the Polytechnic University of Crete, who collaborate closely and often with other national schools. The green cluster mostly consists of Arizona State University, Tsinghua University, Princeton University, etc., and is the second-largest cooperative organization group. Through CiteSpace, a map of institutional collaborations (Fig. 3B), a map of institutional collaboration time zones, and institutions that exploded were generated. In green roofing, 603 institutions published 2986 articles, and the top ten contributing institutions are shown in Table 1. The Chinese Academy of Sciences had the most papers (n = 55), and among the top 10 institutions, all but three were from China, and all were from developed countries in Europe and the United States.

The Chinese Academy of Sciences is ranked first regarding intermediary centrality for both numbers (see Table 2), so its purple outer circle is also most evident in Fig. 3B. The clustering of nodes in the institutional cooperation network indicates frequent and close inter-institutional communication in research on green roofs. The institutions with red circles in Fig. 3C are outbreak institutions, and the top 25 outbreak institutions are shown in Fig. 3D. The yellow nodes in Fig. 3A indicate the institutions where newer literature appears, and combined with Fig. 3D; we know that most of the institutions where newer literature appears are Chinese universities.

3.2.3. *Author collaboration analysis*

By analyzing the structural characteristics of authors in green roofing and their collaboration network, the core authors and their collaboration can be identified. Using Citespace and VOSviewer to generate author collaboration networks, 856 authors have published articles on green roofs (Fig. 4A shows the CiteSpace author network map, and Fig. 4B shows the VOSviewer author network map). The author publishes more articles in the figure when the circle is larger. Jim, C Y published 49 articles and was the most prolific author, followed by Garg, Ankit with 21 articles. Notably, the top 9 authors have a centrality of 0 (Table 2), indicating that the impact of authors on green roofing needs to be improved. Jim, C Y (6.22, 2010–2015), Rowe, D Bradley (6.04, 2006–2012), and Garg, Ankit (5.93, 2019–2023) are the strongest citation explosion of the 3 authors.

As seen in Fig. 4B, the area of green roofing research just recently began to create a few core groups of authors who are leaders in the field, but it has yet to form a substantial collaborative network. In future work, collaboration among authors from different countries should be emphasized. The author collaboration can be found in 14 clusters through Fig. 4C, and the largest cluster consists of 15 authors, including Bou-zeid, Elie, Georgescu, Matei, Li, Dan, etc., for active collaboration and communication, forming the largest author collaboration network.

3.3. *Analysis of research hotspots and frontiers*

3.3.1. *Keywords*

Keywords are the distillation and summation of an article's essential content, and a visual map can highlight scientific trends and concerns growing over time-based on keyword co-occurrence network analysis [26]. In this paper, keyword co-occurrence maps are drawn by CiteSpace combined with VOSviewer. Due to the large sample size, the samples were pruned in CiteSpace Pathfinder to obtain the keyword co-occurrence network (Fig. 5A) by pruning the sliced and merged networks, and then keyword clustering was carried out to obtain the keyword clustering map (Fig. 5C); After setting the threshold value of occurrence number of 10, 454 keywords will fulfill this value in the co-occurrence network analysis using VOSviewer software, and the keyword co-occurrence network is generated (Fig. 5B).

CiteSpace provided the keyword frequencies (see Table 3 for details). "Green roof" placed top in the list of most strongly connected keywords with a total link strength of 8957, "performance" (5261) ranked second, and "UHI" (4670) ranked third. When combined with Fig. 5A, the larger the node, the higher the frequency of keywords. The study's top three keywords had an average year of publication ranging from 2016 to 2019. Generally speaking, there is a direct correlation between the number of occurrences and the total link strength; however, "vegetation" is an exception among the top ten strongest keywords.

In Fig. 5B, the node size is controlled by the frequency of item usage, and the greater the item's label, the more frequently the item is used. Furthermore, there are stronger links between nodes with the same color. Fig. 5B depicts the clustering of keywords, with "green roof" being the biggest node and the center node of cluster 3. "Performance" comes second, with 358 connections between these two keywords, making it the most tightly linked. Fig. 5C shows the CiteSpace keyword clustering map, and we selected the largest 15

Table 1
Volume and centrality of papers published by the top 10 institutions.

Rank	Institution	Count	Centrality
1	Chinese Academy of Sciences	55	0.14
2	The University of Hong Kong	51	0.03
3	Arizona State University	48	0.10
4	The University of Sheffield	47	0.03
5	Agricultural University of Athens	46	0.01
6	The University of Melbourne	44	0.02
7	National University of Singapore	41	0.10
8	University of Calabria	39	0.00
9	Chongqing University	34	0.10
10	University of Columbia	34	0.05

Table 2
Top 10 productive authors on applying green roofs (N = 1259).

Ranking	Publication	Author	Centrality
1	49	Jim, C Y	0
2	21	Garg, Ankit	0
3	19	Rowe, D Bradley	0
4	18	Farrell, Claire	0
5	17	Piro, Patrizia	0
6	16	Belarbi, Rafik	0
7	13	Stovin, Virginia	0
8	13	Nektarios, Panayiotis A	0
9	12	Perez, Gabriel	0
9	12	Mei, Guoxiong	0
9	12	Ntoulas, Nikolaos	0
9	12	Lundholm, Jeremy	0
9	12	Macivor, J Scott	0

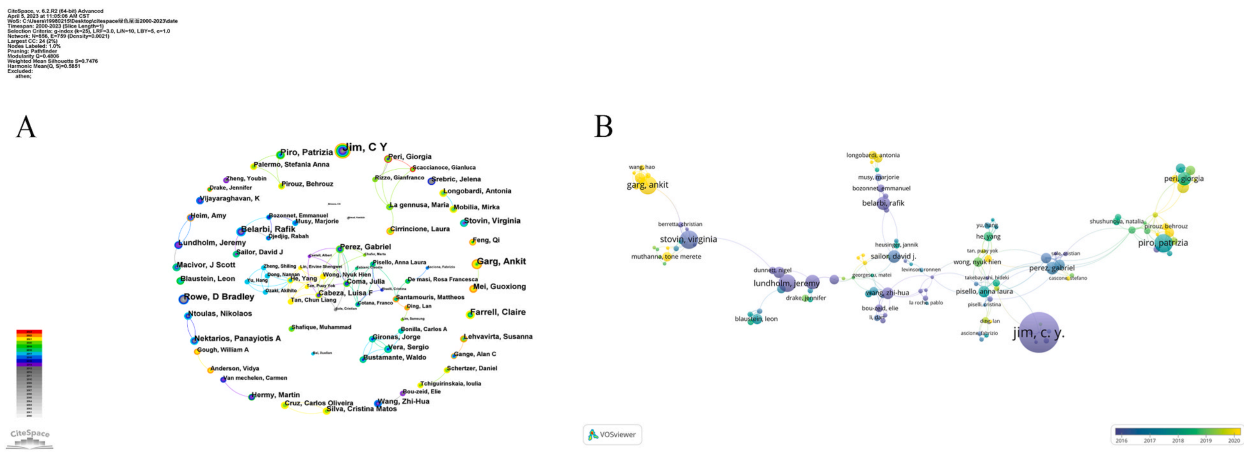

Fig. 4. Author collaboration network.

clusters for visualization and analysis.

The high-frequency words within the yellow clusters include runoff, stormwater management, low-impact development, retention, and hydrologic performance, showing the potential for green roof research to focus on stormwater management aspects. Green roofs have the advantage of intercepting and absorbing rainwater, which improves the urban water environment and reduces flood hazards [27–30]; they can also purify stormwater [31]. An analysis of studies shows that since 1981, about 40.9 % of the articles on green roofs focused on regulating service studies in the context of water [32]. Studies by different authors have also confirmed that factors such as soil type and depth, roof type and slope, local climate and previous precipitation, and vegetation type are the main factors influencing rainwater flow path [28,33–35]. Green roof rainwater retention performance is primarily connected to design configuration and climate, and configuration modification may increase green roof rainwater retention performance [36,37]. Sims, Andrew W. et al. found that dry climates had better retention, but mild and humid climates still had significant performance by examining the retention performance of green roofs in three different climates: humid continental, semi-arid continental, and humid oceanic [38]. Green roofs performed differently in several climatic groups, with significant variations in water quality concentrations, according to studies on urban stormwater management employing them by Akther et al. [39]. The impacts of green roofs on runoff quality are not universally accepted; some studies consider green roof systems to be a source of pollutants, while others consider them to be a sink of pollutants. This has been researched by Vijayaraghavan and Wang. The findings of a study conducted by Vijayaraghavan et al. on four separate real rainfall events and six simulated rainfall events revealed that green roofs may enhance rainwater runoff quality by filtering contaminants and heavy metals from rainfall [40]. Wang et al. argued that integrated measures should be taken to reduce runoff pollution by transforming the source-to-sink journey of pollutants based on the green roof runoff pollutant cycle [41]. In conclusion, different scholars have studied the stormwater management potential of green roofs from different perspectives and confirmed that green roofs are effective.

Expansive green roofs, ecosystem, variety, plants, biodiversity, substrate depth, and soil are among the high-frequency phrases clustered in red, illustrating the green roofs' effects on urban biodiversity. Green roofs may promote urban biodiversity to some extent [42], and the widespread application of green roofs can contribute to increased urban diversity [43]. By increasing the diversity of green roof plants, animal diversity can be increased and made more resistant to disturbance [44,45]; similarly, the diversity of green roofs can be increased through biodiversity design [46]. Green roofs, in particular, boost biodiversity by providing habitat and food for

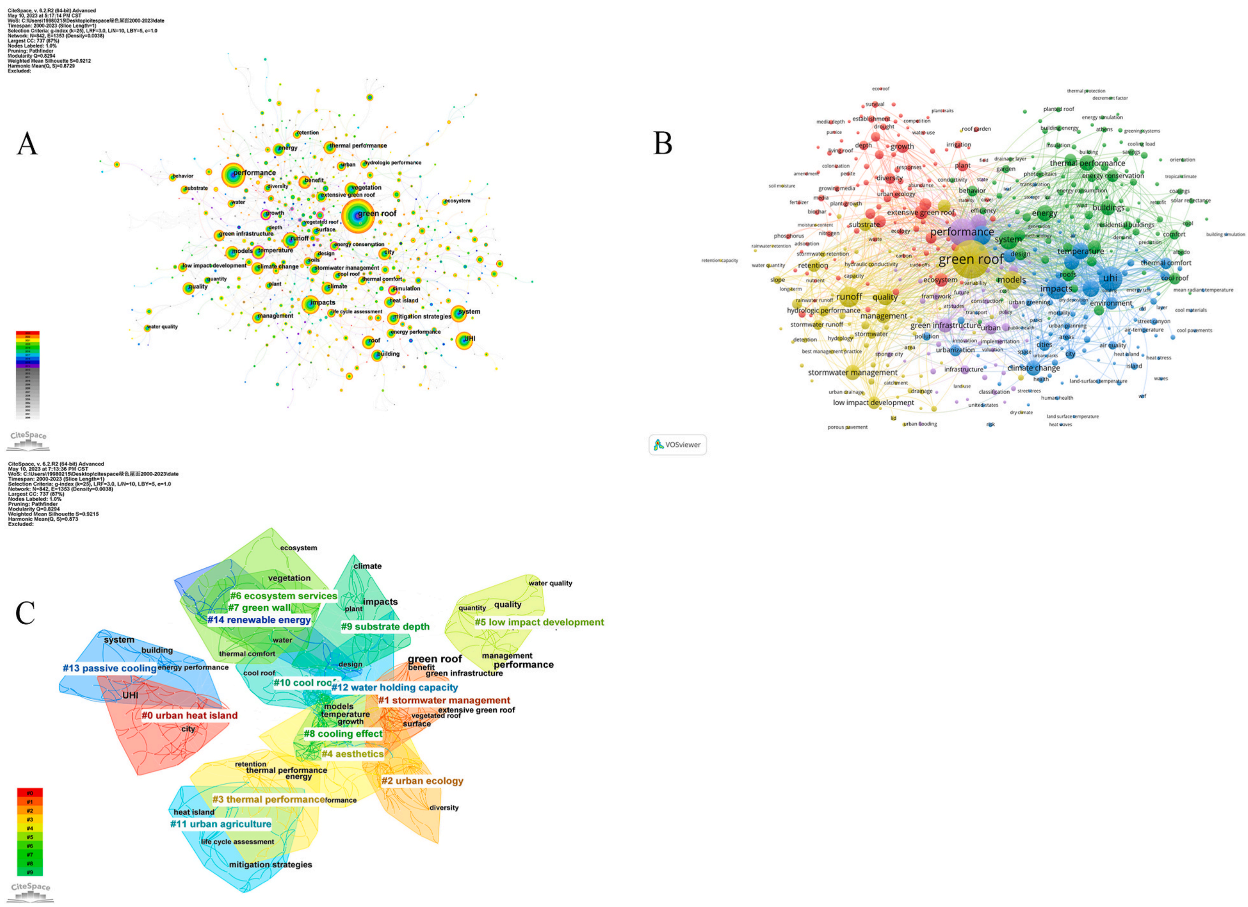

Fig. 5. Keyword analysis.

Table 3
Keywords with the strongest links.

Ranks	Clusters	Keywords	Total Link Strength	Years on average since publication
1	4	Green roof	9075	2017
2	5	performance	5258	2017
3	3	UHI	4670	2018
4	3	impacts	3450	2018
5	4	runoff	3066	2017
6	3	vegetation	2990	2017
7	2	system	2664	2018
8	4	models	2592	2017
9	3	Mitigation strategies	2533	2018
10	3	temperature	2128	2017

animals, making them ecologically significant [7]. For example, floral resources on green roofs can attract wild bees [47] and provide habitat for insects, invertebrates, and birds [48]. Increasing plant diversity can improve the green performance of a roof, which in turn supports richer and more diverse fauna and is more resistant to disturbances [45]. There is a complex relationship between soil and substrate depth and microorganisms [49], the presence of which, in turn, plays a key role in urban ecosystems [50]. According to a study by Fulthorpe, microorganisms can boost the lifespan of green roof plants, the primary producers of ecosystem services [51]. Compared with other sustainable roof technologies, green roofs can provide ecosystem services [52,53], including providing animal and plant habitats and rainwater management. Increasing biodiversity and combining species for the green roof can improve its ecosystem service capacity. Although green roofs can benefit urban biodiversity and contribute to urban ecosystem services, mosquito and plant waste nuisance are recognized as negative impacts [54,55], which still need our attention. Finally, installing green roofs in cities may significantly improve the surrounding environment and expand urban natural areas.

High-frequency terms for green clustering include thermal performance, energy savings, residential buildings, cold roofs, simulation, and mitigation strategies, indicating that green roofs contribute significantly to building energy efficiency. Because of the presence of plants, green roofs can reduce indoor temperature [56]. Green roofs have thermal insulation benefits, and it was found through energy simulations that they can also reduce energy consumption [57], and retrofitting existing buildings with green roofs can achieve energy savings [58]. In dynamic energy models, green roof retrofits in Mediterranean cities have been shown to lower heating and cooling demand by up to 5 % and 16 %, respectively [59], and to increase interior comfort in lower levels of green roofs [60]. Green roofs, whether dense or vast, may reduce air temperature, and the long-term environmental and energy advantages outweigh the cost of installation [61,62]. Taylana Piccinini Scolaro et al. found more economic viability than other roofing systems by analyzing the life cycle costs and benefits of green roofs [63]. However, green roofs do not always provide energy savings related to weather conditions [64]. Green roofs may greatly cut power usage for air conditioning in the rainy tropics [65], and in cold weather, even in the presence of snow, green roofs can be energy efficient [66]. However, green roofs have no significant effect on rainy weather [67]; in desert climates, they are even harmful [68]. Due to their potential to improve building energy efficiency and their role in lowering heating and cooling energy consumption, green roofs are gaining popularity as an alternative [69]. Combining photovoltaics and green roofs can increase the amount of photovoltaic power generated, increasing the availability of clean energy and is a promising alternative energy source [70].

High-frequency blue clustering terms include urban heat island, plants, temperature, climate change, surface, urbanization, and air quality, demonstrating the good function of green roofs in decreasing air pollution and greenhouse gas emissions and minimizing the effects of the urban heat island effect. Plants reduce ambient air temperature and improve air quality through transpiration, evaporation, respiration, and photosynthesis, creating a milder microclimate [71]. Thus, by boosting albedo and using plant transpiration, green roofs can aid in lowering temperatures in metropolitan settings [72,73]. Cooler air generated by green roofs leads to enhanced air movement in street canyons, improving the air quality attached to roads [74]. Gourdji showed that the type of vegetation and increased use of green roofs can improve air quality [75]. Kostadinović, the study of the light green roof can reduce the monthly concentration of PM particles, improving air quality [76]. Green roofs have the potential to decrease carbon dioxide emissions by absorbing and storing air pollutants on a building scale [77]. Public policies must be implemented to encourage the use of semi-intensive and intensive green roofs in cities since they have a good impact on the microclimate of metropolitan areas [78].

Performance, green infrastructure, public health, benefits, and sustainability are some of the high-frequency terms in the purple cluster that highlight the beneficial effects of green roofs on sustainability and public health. To sustain environmental quality, it is becoming increasingly crucial to restore green places [79], and green roofs can help promote the restoration of urban green spaces and improve air and quality of life [80]. Therefore, green roofs are a potential solution for sustainable urban development [81]. Achieving sustainability in green roofs requires, firstly, the selection of plant types with high survival rates; secondly, it is important to choose sustainable irrigation systems [82]. For example, water can be conserved by changing irrigation demand, switching to different irrigation sources, or managing and monitoring irrigation regimes [83]. Vegetable cultivation on green roofs may help urban agriculture remain sustainable [84] without hurting it [85]. With proper management, most vegetables can survive [86], providing food products that can help support and sustain food for urban communities [84]. There is evidence that green roofs offer positive psychological effects [16], especially in large cities where intensive greening of spaces with different plant components is required to improve the mental health of residents [87]. Green roofs are important for public health not only in psychological terms but also in physical terms. Noise is a major problem in urbanized areas, and vegetation and soil can reduce noise pollution [88], especially higher frequency noise [89]. Green roofs not only reduce noise pollution [90], they are beneficial for improving air quality, etc. [91], which in turn is beneficial for the health of urban residents [92].

The clusters in Fig. 5C are also included in the five major clusters in Fig. 5B. For example, the purple clusters in VOSviewer include #4 aesthetics, #7 green wall, and #11 urban agriculture; the blue clusters then cover #0 urban heat island, #8 cooling effect, and #13 passive cooling; the green clusters include #3 thermal performance, #10 cold roof, and #14 renewable energy; the red clusters include #2 urban ecology, #6 ecosystem services, and #9 basement depth; and the yellow clusters include # 1 stormwater management, #5

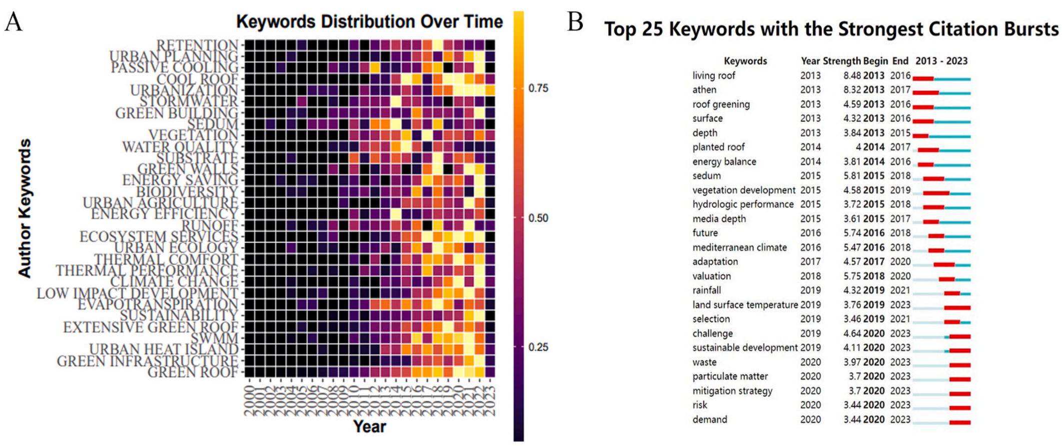

Fig. 6. Keyword heat map and emergence.

low-impact development, and #12 water retention. For this analysis on CiteSpace clustering, see VOSviewer keyword clustering analysis for details.

3.3.2. Research hotspots and prediction

(1) Hot research topics: The keyword heat map (Fig. 6A) was created using R software to depict the distribution of 30 high-frequency keywords across time. The frequency of keyword occurrence was processed by standardization, and the values were distributed between 0 and 1, where each little cell shows the frequency of occurrence of a term in one year. The value of the black cell is the smallest, representing the lowest frequency of keyword occurrence this year. With the color change, the value of the yellow cell is the largest, and its corresponding keyword has the highest frequency of occurrence this year. For example, from 2000 to 2023 (as of March 17), "SWMM" (stormwater management model) and "urban heat island" appear more frequently in 2021 and less frequently in 2022. In 2021 and 2022, the more frequent keywords are energy saving, urban heat island mitigation, biodiversity, and sustainable development.
(2) Cooccurrence analysis of emergent words; keyword emergence is shown in Fig. 6B. As a supplement to keyword co-occurrence analysis, emergent word analysis demonstrates how the research hotspots of green roofing change over time. The red line indicates when keyword bursts were detected, and the blue line displays the time interval. To figure out the research hotspots in the last 10 years, we select the data between 2013 and 2023 and use CiteSpace for keyword co-occurrence, with minimum duration chosen as 3. We finally got 50 keyword bursts and the top 25 co-occurrences. We analyzed the keywords that are still emerging in 2023, such as "land surface temperature," "challenge," "particular matter," sustainable development," "waste," "mitigation strategy," "risk," and "demand." The research on sustainable development, its impact on urban microclimate, and air quality are still hot spots.

4. Co-citation analysis

Co-authorship analysis can show how research teams have contributed to green roofing. There is a frequent citation link between

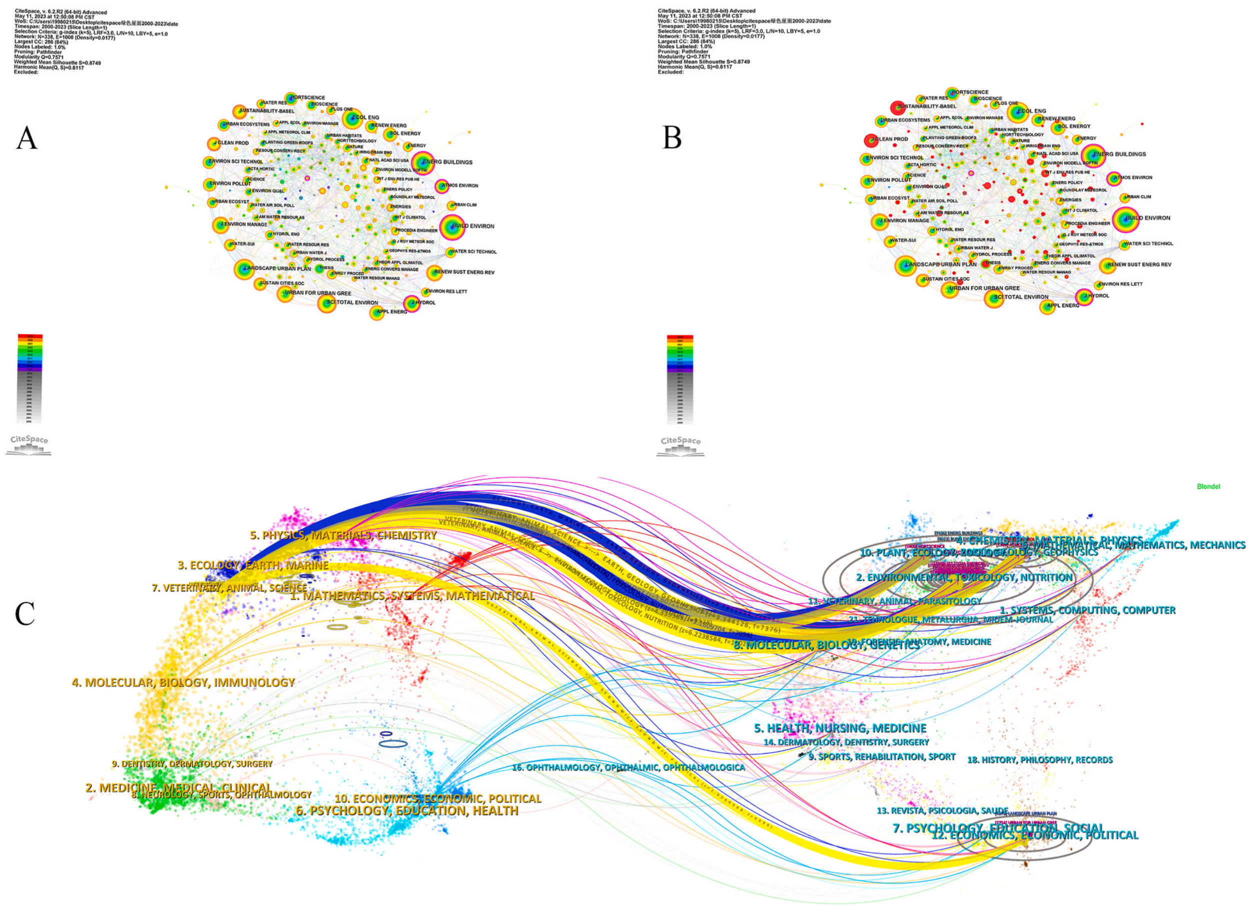

Fig. 7. Journal co-citation analysis network.

two articles when the third article cites them [93]. Co-citation analysis evaluates the organization and representativeness of the discipline and literature the research object represents. It establishes the degree of correlation between journals, literature, and authors through the co-citation relationship and mapping structure between literature [94]. This section uses CiteSpace to examine the common citation patterns across Green Roof journals, authors, and literature. This helps researchers, particularly those new to green roof research, understand the background of the field's general knowledge.

4.1. Analysis of journal co-citations

Creating a co-citation matrix between journals makes it possible to explicitly explain the intricate co-citation interactions between journals [95]. To analyze the organization of academic areas where academic journals serve as the primary communication medium, researchers can use journal co-citation analysis to ascertain the specialty of journals and identify key journals [96]. When different articles cite the same research, other articles form co-citation relationships.

Fig. 7 depicts the journal co-citation visualization network, where Fig. 7A is a co-citation reference network with centrality, where the size of nodes (journals) is proportional to the number of journal co-citations, and high centrality nodes are marked with purple outer circles; Fig. 7B is a co-citation reference network with citation bursts, with burst nodes marked with red rings; and Fig. 7C is a biplot overlay of journals. The node's size indicates the journal's total number of co-citations. The more co-citations a journal has, the more important it is. By comparing the journal and co-citation analysis findings, it was discovered that the most influential journals are LANDSCAPE URBAN PLAN, BUILD ENVIRON, and BIOSCIENCE. They are all well-known academic publications on green roofing that have been highlighted in various review works and should be followed. As for the blast intensity, SUSTAINABILITY-BASEL (58.95, 2021–2023) has the highest blast intensity, followed by HORTSCIENCE (56.69, 2005–2015), PLANTING GREEN ROOFS (50.35, 2006–2015), ENERG BUILDINGS (45.77, 2001–2012) and J ENVIRON QUAL (42.65, 2004–2014).

Journals with the most citations are more essential, showing that they significantly impact green roofing research and are sometimes referred to as core journals. Table 4 shows the 15 most active journals and their citations. Several not externally connected journals may be organically combined by evaluating journal co-citations, demonstrating the interdependence and cross-correlation ships of publications in green roofing. A journal's co-citation relationship and intensity may be used to assess its professional scope and disciplinary character, as well as the fundamental topics of the field. Academic publications may be objectively evaluated by assessing their core or peripheral position in green roof research.

The biplot overlay of journals shows the distribution of themes in academic publications and their location concerning the major research areas. By combining scientific research at a broad scale and referencing mobility patterns across several fields, the bitmap overlay identifies areas of expertise and reveals distribution patterns [97]. Each point on the map represents a journal; the map of the cited journal is on the left, and the map of the cited journal is on the right; the colorful paths connecting them represent the connection mentioned above. The z-scores function normalizes the data to highlight stronger and smoother trajectories, with higher scores shown by thicker lines. There are six major citation pathways (Fig. 7C), two blue and four yellow, and the internal numbers in the ellipse show the number of publications in each discipline. The citation fields on the left are mainly related to ecology, earth, and ocean; the veterinary, animal, and scientific fields have citation paths outward, indicating that this is the most important citation. For example, geology, geophysics, environment, toxicology, and nutrition often cite the blue paths of ecology, earth, and marine journals above. This shows many ways to link the corresponding categories from different disciplines. It is further evident from the biplot overlay analysis that the current research presents an interdisciplinary research situation where a single discipline has bottlenecked the scholars' research. With the help of interdisciplinary technical tools, technical barriers can be broken, and technological progress can be promoted.

Table 4
Top 15 active core journals in green roofing research.

Freq	Centrality	Year	Journal
1658	0.12	2006	LANDSCAPE URBAN PLAN
1947	0.09	2005	BUILD ENVIRON
583	0.06	2008	BIOSCIENCE
1587	0.06	2006	ECOL ENG
1847	0.1	2001	ENERG BUILDINGS
843	0.11	2007	J HYDROL
1171	0.07	2006	SCI TOTAL ENVIRON
669	0.05	2005	HORTSCIENCE
1066	0.06	2010	J ENVIRON MANAGE
637	0.06	2007	ATMOS ENVIRON
251	0.03	2008	URBAN HABITATS
329	0.03	2007	J AM WATER RESOUR AS
1126	0.04	2010	URBAN FOR URBAN GREE
557	0.03	2004	WATER SCI TECHNOL
612	0.02	2010	URBAN ECOSYSTEMS

4.2. Literature co-citation analysis

Co-cited publications must cover related ground. Literature co-citation analysis, which calculates the connections between references, is a valuable technique for determining certain domains' structure and evolutionary trajectories and assessing the development and mapping of any subject topic [98]. A co-citation network graph was created using CiteSpace software to look at the theoretical foundations and evolutionary dynamics of green roofing (Fig. 8A and B). Fig. 8A and B shows the literature co-citation network, where the nodes stand for references, and the size is a direct ratio to the number of times the literature has been cited. Fig. 8A shows nodes in the outer purple ring with high centering, whereas Fig. 8B shows nodes in the inner red ring with citation bursts. References of significant weight in the green roofing are included in Fig. 8A and B.

Table 5 lists the top 15 most co-cited publications, along with the authors, amount of citations, year of publication, and DOI number. Shafique M and Berndtsson JC are the two most mentioned writers. The co-citation analysis is useful for identifying the cited and relevant literature that comprises the field's core body of knowledge. High-centricity material is valued in addition to highly referenced literature. Tall centrality literature is more likely to forge co-citation ties with other literature in the co-citation reference network [99], showing that it has a key position in the study area. The Co referencing network's high centrality nodes are marked with purple outside rings, as seen in Fig. 6A. The top three documents in centrality are Shafique et al. (2018), Vijayaraghavan et al. (2016), and Berndtsson et al. (2010). Shafique et al. (2018) study demonstrates how green roofs function in various contexts and how they lower energy and rainfall costs and enhance environmental performance [100]. The study by Vijayaraghavan et al. (2016) identifies knowledge gaps in green roof technology and the necessity for localized research in poor countries to build a viable green roof method that considers the influence of growing substrates, vegetation, and drainage layers [101]. Berndtsson et al. (2010) explain the significance of green roofs in urban drainage while addressing water quantity and quality control [33]. Finally, references with high centrality and citation rates are critical for advancing our understanding of green roofs.

4.3. Author co-citation analysis

The field cannot progress without the full support of renowned professionals and researchers. During the development of green roofing, several renowned researchers have pushed the derivation and growth of the topic. The simultaneous citation of two (or more) authors in one or more subsequent articles is known as author co-citation, and it establishes a connection of co-citation. Author co-citation analysis assists us in identifying highly cited authors and analyze the authors' interdisciplinary backgrounds and research areas to find the most influential contributing authors and the distribution of highly referenced authors in that research field. Fig. 9 depicts the visualization network. The nodes represent writers, while the connecting lines show co-citation connections. The larger the node, the more citations the author has in the network and the greater the author's influence. Fig. 9A depicts a co-cited reference network with centrality, where the size of the node (author) is proportional to the number of times the author has been co-cited, and a purple outer ring denotes the high centrality node; Fig. 9B shows a co-cited reference network with citation burst, where a red ring denotes the burst node. As illustrated in Fig. 9, ANONYMOUS has the most citations with 1526, followed by GETTER KL with 695.

Scholars reference articles for several reasons, including admiration for the pioneer, appreciation for similar work, acknowledgment of instruments or research techniques, respect for colleagues, and offering context for the research. These findings indicate that the authors as mentioned above' work has made a major addition to the field of green roofing, which will have an even greater influence on future studies.

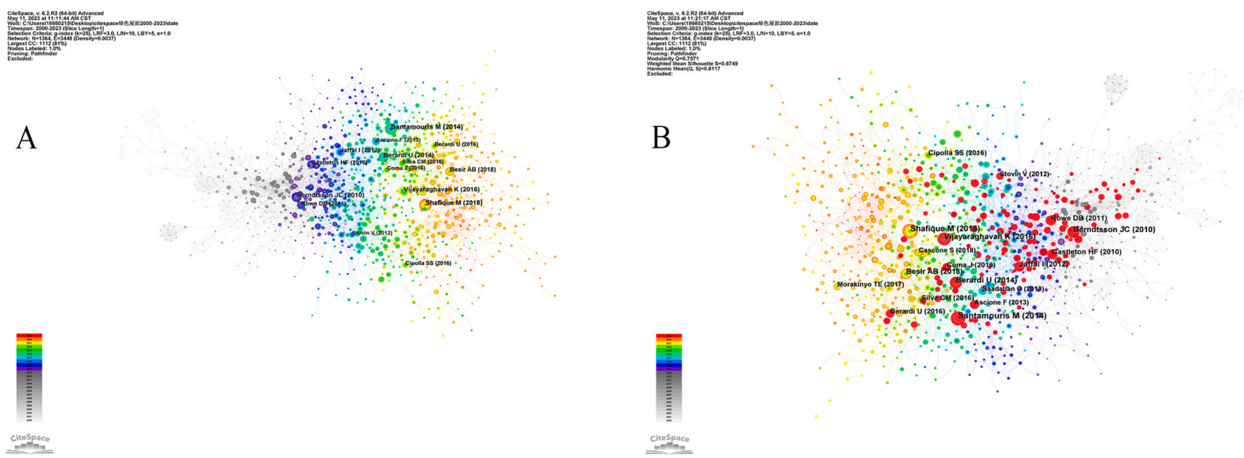

Fig. 8. Co-citation chart of literature.

Table 5
Top 15 references of green roofing-related studies.

Freq	Centrality	Year	Author	DOI
198	0.14	2018	Shafique M	10.1016/j.rser.2018.04.006
138	0.13	2010	Berndtsson JC	10.1016/j.ecoleng.2009.12.014
127	0.11	2018	Besir AB	10.1016/j.rser.2017.09.106
62	0.11	2012	Rowe DB	10.1016/j.landurbplan.2011.11.010
77	0.06	2016	Silva CM	10.1016/j.enbuild.2016.01.012
160	0.14	2016	Vijayaraghavan K	10.1016/j.rser.2015.12.119
39	0.07	2007	Getter KL	10.1016/j.ecoleng.2007.06.004
51	0.06	2010	Dvorak B	10.1016/j.landurbplan.2010.04.009
32	0.04	2020	Bevilacqua P	10.1016/j.renene.2020.01.085
29	0.03	2007	Carter T	10.1016/j.landurbplan.2006.06.005
50	0.07	2010	Lundholm J	10.1371/journal.pone.0009677
78	0.06	2016	Berardi U	10.1016/j.enbuild.2016.03.021
37	0.03	2008	Wolf D	10.1016/j.ecoleng.2008.02.008
61	0.02	2018	Cascone S	10.1016/j.buildenv.2018.03.052
44	0.05	2006	Mentens J	10.1016/j.landurbplan.2005.02.010

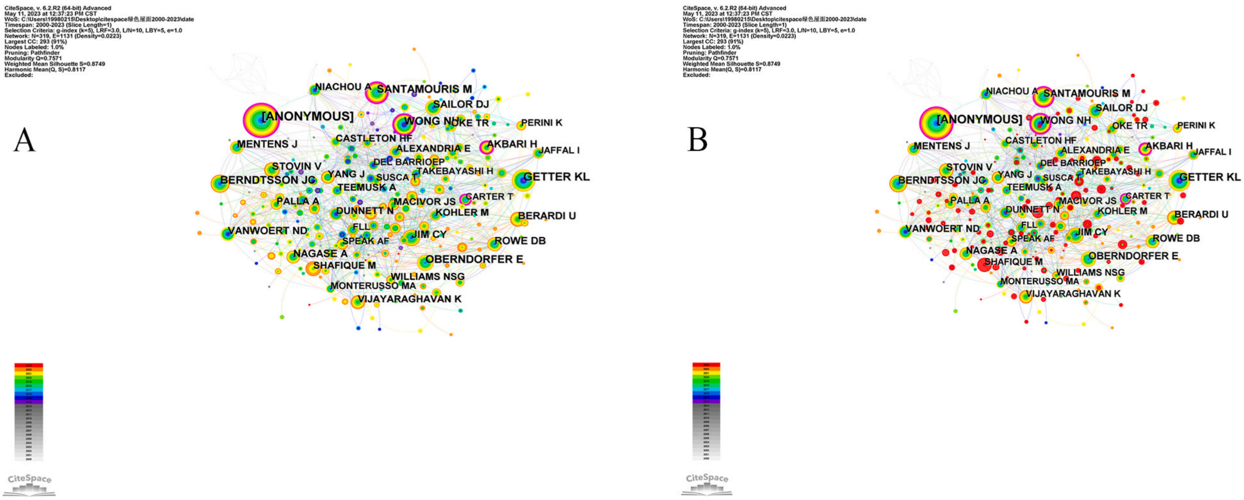

Fig. 9. Co-citation of authors.

5. Discussion and analysis of further research topics

(1) Synergistic development with other green infrastructures from an urban planning perspective. Green roofs, as a component of urban green infrastructure, many of these functions need to be used in combination with other urban green spaces to better play their role. For example, rainwater runoff management, compared with the single role of green roofs, combined with vertical green facilities, urban artificial wetlands, green belts, etc., can better play its role in alleviating rainwater runoff. Regarding urban biodiversity, the kind of green roofs, plant species, and whether they can complement existing green infrastructure must be examined from an urban planning standpoint.

(2) Localization study of green roofs. In 3.3.1, we investigated how weather affects how much energy green roofs save and how much precipitation runs off them. The performance varies in different climatic conditions, in addition to the different abilities of plants to survive in different climates and the different levels of economic development in each country. As a result, it's important to carry out regional studies on green roofs and create green roof systems that are appropriate for the country's climate.

(3) Research on photovoltaic green roofs. Photovoltaic green roofs combine the advantages of P.V. and green roofs, and their combined use may lower energy consumption, lessen the impact of the urban heat island, and positively affect the environment, the economy, and society [102]. Compared to G.R. and P.V. systems alone, P.V. green roofs generate shorter payback periods for energy and carbon emissions [103]. However, both G.R. and P.V. systems have substantial initial prices, which limit their implementation in certain countries, necessitating assessing P.V. green roof life-cycle costs and benefits. Of course, with the breakthrough of calcium titanite solar panel technology and cost reduction, P.V. green roofs will have greater advantages. Therefore, a deeper study of the topic can be conducted.

6. Conclusion

This study combines the advantages of CiteSpace, VOSviewer, and bibliometric software packages. Using green roofing as the research topic, it uses a comprehensive bibliometric approach to visualize and analyze publications in the WOS database between 2000 and 2023. Firstly, based on the pattern in the number of papers published each year, the general development tendency is slow at first, then rapid, with a minor drop by 2022. Secondly, the analysis was conducted from macro, meso, and micro levels of collaboration on green roofing, i.e., from national collaboration, institutional collaboration, and author collaboration; China and the United States are the two countries with the most research on green roofing, and their collaboration is also the closest; institutional analysis reveals that CAS has the most publications and its intermediary centrality is also the highest, and the majority of the top ten research institutions are from developed countries; author collaboration level The authors' collaboration level, which has not yet formed a large-scale collaborative network. Then, the keywords were analyzed, including keyword frequency, keyword co-occurrence network, and research hotspots. The top three keywords were "green roof," "performance," and "UHI," which somewhat resembled the researchers' previous areas of Interest. The keyword co-occurrence analysis shows that green roof research is divided into five major areas: 1) potential for water conservation, precipitation, and flood reduction, 2) impact on urban biodiversity, 3) building energy conservation, 4) positive effects on lowering air pollution and greenhouse gas emissions, attenuating the urban heat island effect, and 5) positive effects on sustainable development and public health. The keyword hotspots and emergences were analyzed, and their main areas of involvement remained in these five areas. Finally, co-citation analysis included journal, literature, and author co-citation analysis. The top 15 articles with the highest number of co-citations came from the literature co-citation analysis (see Table 5); the co-citation analysis of authors revealed that ANONYMOUS and GETTER KL have the highest number of citations. The three most influential journals were LANDSCAPE URBAN PLAN, BUILD ENVIRON, and BIOSCIENCE. In addition, several topics worth further research were proposed based on the subject structure, high-frequency keywords, keyword emergence, and buzzwords. The bibliometric analysis based on CiteSpace, VOSviewer has the following advantages: 1) evaluation and visualization through different items, 2) its clustering can better analyze different research areas, and 3) high-frequency keywords and keyword emergence can better reveal research hotspots and trends. Because of this, we can come up with topics that are worthy of further research. However, this study has certain limitations. Firstly, CiteSpace and Vosviewer are commonly used research methods for review, but the data collection pathways need to be more diverse. Therefore, we plan to try other innovative review research methods in the future. Secondly, the data we selected comes from the Web of Science and has not been extended to other languages. Therefore, we can collect data from different languages in future work to make the research more comprehensive.

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Data availability statement

The analysis of some of the original datasets generated in the current study was sourced from the database Web of Science at www.webofscience.com. The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Hongbing Li: Methodology, Resources, Supervision, Writing – review & editing. **Yuran Xiang:** Methodology, Writing – original draft, Writing – review & editing. **Wanjun Yang:** Formal analysis, Visualization. **Tao Lin:** Investigation, Software. **Qiankun Xiao:** Conceptualization, Investigation, Validation. **Guoquan Zhang:** Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] U. Berardi, A.G. HaffarianHoseini, State-of-the-art analysis of the environmental benefits of green roofs, Appl. Energy 115 (2014) 411–428.

[2] Muhammad Shafique, Anam Azam, Muhammad Rafiq, Muhammad Ateeq, Xiaowei Luo, An overview of life cycle assessment of green roofs, J. Clean. Prod. 250 (2020) 119471.

[3] Maria Manso, Inês Teotónio, Cristina Matos Silva, Carlos Oliveira Cruz, Green roof and green wall benefits and costs: a review of the quantitative evidence, Renewable Sustainable Energy Rev. 135 (2021) 110111.

[4] Wen Liu, Yuguo Qian, Lei Yao, Qi Feng, Bernard A. Engel, Weiping Chen, Tengfei Yu, Identifying city-scale potential and priority areas for retrofitting green roofs and assessing their runoff reduction effectiveness in urban functional zones, J. Clean. Prod. 332 (2022).
[5] Zhangjie Peng, Brad Garner, Virginia Stovin, Two green roof detention models applied in two green roof systems, J. Hydrol. Eng. 27 (2) (2022) 4021049.
[6] Muhammad Shafique, Reeho Kim, Kyung-Ho, Kwon, Green roof for stormwater management in a highly urbanized area: the case of seoul, Korea, Sustainability 10 (3) (2018) 584.
[7] E.I.F. Wooster, R. Fleck, F. Torpy, D. Ramp, P.J. Irga, Urban green roofs promote metropolitan biodiversity: a comparative case study, Build. Environ. 207 (2022).
[8] Sékou F.M. Coulibaly, Christine Aubry, Fanny Provent, Sophie Rousset-Rouvière, Sophie Joimel, The role of green roofs as urban habitats for biodiversity modulated by their design: a review, Environ. Res. Lett. 18 (7) (2023) 073003.
[9] Zaloa Azkorra-Larrinaga, Naiara Romero-Antón, Koldobika Martin-Escudero, Gontzal Lopez-Ruiz, Environmentally sustainable green roof design for energy demand reduction, Buildings 13 (1846) (2023) 1846.
[10] P. La Roche, U. Berardi, Comfort and energy savings with active green roofs, Energy Build. 82 (1) (2014) 492–504.
[11] Hashem Akbari, Dionysia Kolokotsa, Three decades of urban heat islands and mitigation technologies research, Energy Build. 133 (1) (2016) 834–842.
[12] Jana Brenner; Stefan Schmidt & Christian Albert. Localizing and prioritizing roof greening opportunities for urban heat island mitigation: insights from the city of Krefeld, Germany[J].Landsc. Ecol.,Vol.38(7): 1697-1712.
[13] M. Moghbel, R. Erfanian Salim, Environmental benefits of green roofs on microclimate of Tehran with specific focus on air temperature, humidity and CO_2 content, Urban Clim. 20 (2017) 46–58.
[14] Yongwon Seo, Youjeong Kwon, Jun Shik Hwang, Dong Kook Woo, A comparative experimental study of green roofs based on radiation budget and surface energy balance, KSCE J. Civ. Eng. 27 (4) (2023) 1866–1880.
[15] Tiana C.L. Moreira, Jefferson L. Polize, Marceli Brito, F da Demostenes, Silva Filho, Alexandre D P Chiavegato Filho, Maria Carmem Viana, Laura Helena Andrade, Thais Mauad, Assessing the impact of urban environment and green infrastructure on mental health: results from the São Paulo Megacity Mental Health Survey, J. Expo. Sci. Environ. Epidemiol. 32 (2) (2022) 205–212.
[16] Kathryn J.H. Williams, Kate E. Lee, Leisa Sargent, Katherine A. Johnson, John Rayner, Claire Farrell, Rebecca E. Miller, Nicholas S.G. Williams, Appraising the psychological benefits of green roofs for city residents and workers, Urban For. Urban Green. 44 (2019).
[17] X. Zou, W.L. Yue, H.L. Vu, Visualization and analysis of mapping knowledge domain of road safety studies, Accid. Anal. Prev. 118 (2018) 131–145.
[18] X. Zou, H.L. Vu, Mapping the knowledge domain of road safety studies: a scientometric analysis, Accid. Anal. Prev. 132 (2019) 105243.
[19] X.L. Pan, E.J. Yan, M. Cui, W.N. Hua, Examining the usage, citation and diffusion patterns of bibliometric mapping software: a comparative study of three tools, J. Informetr. 12 (2) (2018) 481–493.
[20] Huakun Hu, Wendong Xue, Peng Jiang, Yong Li, Bibliometric analysis for ocean renewable energy: an comprehensive review for hotspots, frontiers, and emerging trends, Renew. Sustain. Energy Rev. 167 (2022) 112739.
[21] Nees Jan van Eck, Ludo Waltman, Software survey: VOSviewer, a computer program for bibliometric mapping, Scientometrics 84 (2) (2010) 523–538.
[22] C. Chen, Science mapping: a systematic review of the literature, J. Data Inf. Sci. 2 (2017) 1–40.
[23] C.M. Chen, Z.G. Hu, S.B. Liu, H. Tseng, Emerging trends in regenerative medicine: a scientometric analysis in CiteSpace, Expet Opin. Biol. Ther. 12 (5) (2012) 593–608.
[24] M. Aria, C. Bibliometrix Cuccurullo, An R-tool for comprehensive science mapping analysis, J. Informetr. 11 (4) (2017) 959–975.
[25] N. Tsolakis, L. Anthopoulos, N. Tsolakis, L. Anthopoulos, Eco-cities: an integrated system dynamics framework and a concise research taxonomy, Sustain. Cities Soc. 17 (2015) 1–14.
[26] C. Chen, Science mapping: a systematic review of the literature, J. Data Inf. Sci. 2 (2017) 1–40.
[27] Silva Joana, Teresa A. Paço, Vítor Sousa, Cristina M. Silva, Hydrological performance of green roofs in mediterranean climates: a review and evaluation of patterns, Water 13 (18) (2021) 2600.
[28] H. Yin, F. Kong, I. Dronova, Hydrological performance of extensive green roofs in response to different rain events in a subtropical monsoon climate, Landsc. Ecol. Eng. 15 (2019) 297–313.
[29] M.A. Monterusso, D.B. Rowe, D.K. Russell, C.L. Rugh, Runoff water quantity and quality from green roof systems, Acta Hortic. 639 (639) (2005) 369–376.
[30] Cristina M. Monteiro, Ana Mafalda Mendes, Cristina Santos, Green roofs as an urban NbS strategy for rainwater retention: influencing factors—a review, Water 15 (2023) 2787.
[31] K. Vijayaraghavan, Green roofs: a critical review on the role of components, benefits, limitations and trends, Renewable Sustainable Energy Rev. 57 (2016) 740–752.
[32] Hongqing Liu, Fanhua Kong, Haiwei Yin, Ariane Middel, Xiandi Zheng, Jing Huang, Hairong Xu, Ding Wang, Zhihao Wen, Impacts of green roofs on water, temperature, and air quality: a bibliometric review, Build. Environ. 196 (2021) 107794.
[33] Czemiel Berndtsson, Justyna, Green roof performance towards management of runoff water quantity and quality: a review, Ecol. Eng. 36 (4) (2010) 351–360.
[34] S.S. Cipolla, M. Maglionico, I. Stojkov, A long-term hydrological modeling of an extensive green roof by means of SWMM, Ecol. Eng. 95 (2016) 876–887.
[35] Florence Rezende Leite, Maria Lúcia Pereira Antunes, Green roof recent designs to runoff control: a review of building materials and plant species used in studies, Ecol. Eng. 189 (2023) 106924.
[36] Jing Yan, Shouhong Zhang, Jianjun Zhang, Sunxun Zhang, Chengyu Zhang, Hang Yang, Renzhongyuan Wang, Liangyi Wei, Stormwater retention performance of green roofs with various configurations in different climatic zones, J. Environ. Manag. 319 (2022) 115447.
[37] Jun Wang, Ankit Garg, Ning Liu, Deqiang Chen, Guoxiong Mei, Experimental and numerical investigation on hydrological characteristics of extensive green roofs under the influence of rainstorms, Environ. Sci. Pollut. Control Ser. 29 (35) (2022) 53121–53136.
[38] Andrew W. Sims, Clare E. Robinson, Charles C. Smart, James A. Voogt, Geoffrey J. Hay, Jeremey T. Lundholm, Brandon Powers, Denis M. O'Carroll, Retention performance of green roofs in three different climate regions, J. Hydrol. 542 (2016) 115–124.
[39] M. Akther, Jianxun He, A. Chu, Jian Huang, B. van Duin, A review of green roof applications for managing urban stormwater in different climatic zones, Sustainability 10 (8) (2018) 1–28.
[40] K. Vijayaraghavan, U.M. Joshi, R. Balasubramanian, A field study to evaluate runoff quality from green roofs, Water Res. 46 (4) (2012) 1337–1345.
[41] H.B. Wang, J. Qin, Y.H. Hu, Are green roofs a source or sink of runoff pollutants? Ecol. Eng. 107 (2017) 65–70.
[42] Linwen Wang, Hui Wang, Yuncai Wang, Yue Che, Zhiwei Ge, Lingfeng Mao, The relationship between green roofs and urban biodiversity: a systematic review, Biodivers. Conserv. 31 (7) (2022) 1771.
[43] Stefan Schrader, Matthias Böning, Soil formation on green roofs and its contribution to urban biodiversity with emphasis on Collembolans, Pedobiologia 50 (4) (2006) 347–356.
[44] Diego Fabián, Ezequiel González, Sánchez Domínguez, María Virginia, Adriana Salvo, María Silvina Fenoglio, Towards the design of biodiverse green roofs in Argentina: assessing key elements for different functional groups of arthropods, Urban For. Urban Green. 61 (2021) 127107.
[45] Susan C. Cook-Patton, Taryn L. Bauerle, Potential benefits of plant diversity on vegetated roofs: a literature review, J. Environ. Manag. 106 (2012) 85–92.
[46] Sydney Gonsalves, Starry Olyssa, Szallies Alexander, Stephan Brenneisen, Correction to: the effect of urban green roof design on beetle biodiversity, Urban Ecosyst. 25 (1) (2022) 221.
[47] Sophie Kratschmer, Monika Kriechbaum, Bärbel Pachinger, Buzzing on top: linking wild bee diversity, abundance, and traits with green roof qualities, Urban Ecosyst. 21 (3) (2018) 429–446.
[48] Dustin R. Partridge, J. Alan Clark, Urban green roofs provide habitat for migrating and breeding birds and their arthropod prey, PLoS One 13 (8) (2018) 1–23.
[49] Molineux, J. Chloe, Alan C. Gange, Darryl J. Newport, Using soil microbial inoculations to enhance substrate performance on extensive green roofs, Sci. Total Environ. 580 (1) (2017) 846–856.
[50] G Droz Anna, R. Reid, Coffman, Andrew C. Eagar, Christopher B. Blackwood, Drivers of fungal diversity and community biogeography differ between green roofs and adjacent ground-level green space, Environ. Microbiol. (2022).

[51] R. Fulthorpe, J.S. MacIvor, P. Jia, S.L.E. Yasui, The green roof microbiome: improving plant survival for ecosystem service delivery(Review), Front. Ecol. Evol. 6 (2018).
[52] Garland Xie, Jeremy T. Lundholm, J. Scott MacIvor, Phylogenetic diversity and plant trait composition predict multiple ecosystem functions in green roofs, Sci. Total Environ. 628–629 (1) (2018) 1017–1026.
[53] Cristina Matos Silva, Fátima Bernardo, Maria Manso, Isabel Loupa Ramos, Green spaces over a roof or on the ground, does it matter? The perception of ecosystem services and potential restorative effects, Sustainability 15 (5334) (2023) 5334.
[54] G.K.L. Wong, C.Y. Jim, Urban-microclimate effect on vector mosquito abundance of tropical green roofs, Build. Environ. 112 (1) (2017) 63–76.
[55] Ling Chui Hui, C.Y. Jim, Yuhong Tian, Public views on green roofs and green walls in two major Asian cities and implications for promotion policy, Urban For. Urban Green. 70 (2022) 127546.
[56] Arna Ganguly, Debashish Chowdhury, Subhasis Neogi, Performance of building roofs on energy efficiency – a review, Energy Proc. 90 (1) (2016) 200–208.
[57] Cai Lu, Xiao-Ping Feng, Jing-Yan Yu, Qian-Chao Xiang, Rui Chen, Reduction in carbon dioxide emission and energy savings obtained by using a green roof, Aerosol Air Qual. Res. 19 (11) (2019) 2432–2445.
[58] Stefano Catania Cascone, Federico Gagliano, Antonio Sciuto Gaetano, A comprehensive study on green roof performance for retrofitting existing buildings, Build. Environ. 136 (1) (2018).
[59] Marinos Karteris, Ifigeneia Theodoridou, Giorgos Mallinis, Emmanouel Tsiros, Apostolos Karteris, Towards a green sustainable strategy for Mediterranean cities: assessing the benefits of large-scale green roofs implementation in Thessaloniki, Northern Greece, using environmental modeling, GIS, and very high spatial resolution remote sensing data, Renewable Sustainable Energy Rev. 58 (2016) 510–525.
[60] U. Berardi, The outdoor microclimate benefits and energy saving resulting from green roofs retrofits, Energy Build. 121 (2016) 217–229.
[61] Amir Aboelata, Assessment of green roof benefits on buildings' energy-saving by cooling outdoor spaces in different urban densities in arid cities, Energy 219 (2021) 119514.
[62] C.Y. Jim, L.L.H. Peng, Weather effect on thermal and energy performance of an extensive tropical green roof, Urban For. Urban Green. 11 (1) (2012) 73–85.
[63] Taylana Piccinini Scolaro, Enedir Ghisi, Life cycle assessment of green roofs: a literature review of layers materials and purposes, Sci. Total Environ. 829 (2022) 154650.
[64] Lilliana L.H. Peng, Xiaoshan Yang, Yunfei He, Zhenyu Hu, Tianjing Xu, Zhidian Jiang, Lingye Yao, Thermal and energy performance of two distinct green roofs: temporal pattern and underlying factors in a subtropical climate, Energy Build. 185 (1) (2019) 247–258.
[65] S.W. Tsang, C.Y. Jim, Theoretical evaluation of thermal and energy performance of tropical green roofs, Energy 36 (5) (2011) 3590–3598.
[66] M. Zhao, J. Srebric, Assessment of green roof performance for sustainable buildings under winter weather conditions, J. Cent. S. Univ. Technol. 19 (3) (2012) 639–644 (English Edition).
[67] L. Jiang, M.F. Tang, Thermal analysis of extensive green roofs combined with night ventilation for space cooling, Energy Build. 156 (2017) 238–249.
[68] Tiziana Susca, Green roofs to reduce building energy use? A review on key structural factors of green roofs and their effects on urban climate, Build. Environ. 162 (2019) 106273.
[69] Evangelos Koroxenidis, Theodoros Theodosiou, Comparative environmental and economic evaluation of green roofs under Mediterranean climate conditions – extensive green roofs a potentially preferable solution, J. Clean. Prod. 311 (2021) 127563.
[70] Prakhar Talwar, Nikita Verma, Hemant Khatri, Pratiksha Dadaji Ahire, Gaurav Chaudhary, Christoph Lindenberger, Vivekanand Vivekanand, A systematic review of photovoltaic-green roof systems in different climatic conditions focusing on sustainable cities and societies, Sustain. Cities Soc. 98 (2023) 104813.
[71] Maria Manso, Inês Teotónio, Cristina Matos Silva, Carlos Oliveira Cruz, Green roof and green wall benefits and costs: a review of the quantitative evidence, Renewable Sustainable Energy Rev. 135 (2021) 110111.
[72] Mostafa Razzaghmanesh, Simon Beecham, Telma Salemi, The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia, Urban For. Urban Green. 15 (1) (2016) 89–102.
[73] Lino Sanchez, Tony G. Reames, Cooling detroit: a socio-spatial analysis of equity in green roofs as an urban heat island mitigation strategy, Urban For. Urban Green. 44 (2019).
[74] Jong-Jin Baik, Kyung-Hwan Kwak, Seung-Bu Park, Young-Hee Ryu, Effects of building roof greening on air quality in street canyons, Atmos. Environ. 61 (2012) 48–55.
[75] Shannon Gourdji, Review of plants to mitigate particulate matter, ozone, as well as nitrogen dioxide air pollutants and applicable recommendations for green roofs in Montreal, Quebec, Environ. Pollut. 241 (2018) 378–387.
[76] Danka Kostadinović, Marina Jovanović, Vukman Bakić, Nenad Stepanić, Mitigation of urban particulate pollution using lightweight green roof system, Energy Build. 293 (2023) 113203.
[77] Muhammad Shafique, Xiaolong Xue, Xiaowei Luo, An overview of carbon sequestration of green roofs in urban areas, Urban For. Urban Green. 47 (2019) 126515.
[78] Sergio S. Herrera-Gomez, Abel Quevedo-Nolasco, Luis Pé rez-Urrestarazu, The role of green roofs in climate change mitigation. A case study in Seville (Spain), Build. Environ. 123 (2017) 575–584.
[79] Kristin L. Getter, D. Bradley Rowe, The role of extensive green roofs in sustainable development, Hortscience 41 (5) (2006) 1276–1285.
[80] M. Hajilou, M. Ebrahimi, Utilizing green roofs to mitigate urban environmental challenges: application to Mashhad Metropolitan Area, Int. J. Environ. Sci. Technol. 20 (2) (2023) 1463–1478.
[81] Aseel Hussien, Nusrat Jannat, Emad Mushtaha, Ahmed Al-Shammaa, A holistic plan of flat roof to green-roof conversion: towards a sustainable built environment, Ecol. Eng. 190 (2023) 106925.
[82] Mohsen Shahmohammad, Majid Hosseinzadeh, Bruce Dvorak, Farzaneh Bordbar, Shahmohammadmirab Hamid, Nasrin Aghamohammadi, Sustainable green roofs: a comprehensive review of influential factors, Environ. Sci. Pollut. Res. Int. 29 (52) (2022) 1–27.
[83] Carmen Van Mechelen, Thierry Dutoit, Hermy Martin, Adapting green roof irrigation practices for a sustainable future: a review, Sustain. Cities Soc. 19 (2015) 74–90.
[84] Stuart Alan Walters, Karen Stoelzle Midden, Sustainability of urban agriculture: vegetable production on green roofs, Agriculture (Switzerland) 8 (11) (2018) 1–16.
[85] Leigh J. Whittinghill, D. Bradley Rowe, The role of green roof technology in urban agriculture, Renew. Agric. Food Syst. 27 (4) (2012) 314–322.
[86] Cristiano Elena, Roberto Deidda, Francesco Viola, The role of green roofs in urban Water-Energy-Food-Ecosystem nexus: a review, Sci. Total Environ. 756 (2021) 143876.
[87] Tiana C.L. Moreira, Jefferson L. Polize, Marceli Brito, F da Demostenes, Silva Filho, Alexandre D P Chiavegato Filho, Maria Carmem Viana, Laura Helena Andrade, Thais Mauad, Assessing the impact of urban environment and green infrastructure on mental health: results from the São Paulo Megacity Mental Health Survey, J. Expo. Sci. Environ. Epidemiol. 32 (2) (2022) 205–212.
[88] Gaochuan Zhang, Bao-Jie He, Towards green roof implementation: drivers, motivations, barriers and recommendations, Urban For. Urban Green. 58 (2021) 126992.
[89] Timothy Van Renterghem, Dick Botteldooren, Reducing the acoustical facade load from road traffic with green roofs, Build. Environ. 44 (5) (2009) 1081–1087.
[90] Giouli Mihalakakou, Manolis Souliotis, Maria Papadaki, Penelope Menounou, Panayotis Dimopoulos, Dionysia Kolokotsa, John A. Paravantis, Aris Tsangrassoulis, Giorgos Panaras, Evangelos Giannakopoulos, Spiros Papaefthimiou, Green roofs as a nature-based solution for improving urban sustainability: progress and perspectives, Renew. Sustain. Energy Rev. 180 (2023) 113306.
[91] Nadia Balvedi, Thalita Giglio, Influence of green roof systems on the energy performance of buildings and their surroundings, J. Build. Eng. 70 (2023) 106430.
[92] Francesca Ugolini, Luciano Massetti, Pedro Calaza-Martínez, Paloma Cariñanos, Cynnamon Dobbs, Silvija Krajter Ostoić, Ana Marija Marin, David Pearlmutter, Hadas Saaroni, Ingrida Šaulienė, Maja Simoneti, Andrej Verlič, Dijana Vuletić, Giovanni Sanesi, Effects of the COVID-19 pandemic on the use and perceptions of urban green space: an international exploratory study, Urban For. Urban Green. 56 (2020) 126888.

[93] Y.W. Chang, M.H. Huang, C.W. Lin, Evolution of research subjects in library and information science based on keyword, bibliographical coupling, and co-citation analyses, Scientometrics 105 (3) (2015) 2071–2087.
[94] J. Behrend, M. Eulerich, H.M. Alqudah, N.A. Amran, H. Hassan, The evolution of internal audit research: a bibliometric analysis of published documents (1926–2016), Account. Hist. Rev. 29 (1) (2019) 103–139.
[95] Lijun Yang, Liangxiu Han, Naxin Liu, A new approach to journal co-citation matrix construction based on the number of co-cited articles in journals, Scientometrics 120 (2) (2019) 507–517.
[96] C.P. Hu, J.M. Hu, Y. Gao, Y.K. Zhang, A journal co-citation analysis of library and information science in China, Scientometrics 86 (3) (2011) 657–670.
[97] C. Chen, L. Leydesdorff, Patterns of connections and movements in dual-map overlays: a new method of publication portfolio analysis, J. Am. Soc. Inf. Sci. Technol. 65 (2) (2014) 334–351.
[98] H.C. Liao, M. Tang, L. Luo, C.Y. Li, F. Chiclana, X.J. Zeng, A bibliometric analysis and visualization of medical big data research, Sustainability 10 (1) (2018) 166.
[99] Chaomei Chen, CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature, J. Am. Soc. Inf. Sci. Technol. 57 (3) (2006) 359–377.
[100] M. Shafique, R. Kim, M. Rafiq, Green roof benefits, opportunities, and challenges – a review, Renewable Sustainable Energy Rev. 90 (2018) 757–773.
[101] K. Vijayaraghavan, Green roofs: a critical review on the role of components, benefits, limitations and trends, Renewable Sustainable Energy Rev. 57 (2016) 740–752.
[102] Valeria Todeschi, Guglielmina Mutani, Lucia Baima, Marianna Nigra, Matteo Robiglio, Smart solutions for sustainable cities—the Re-coding experience for harnessing the potential of urban rooftops, Appl. Sci. 10 (7112) (2020) 7112.
[103] Zhaozhi Wang, Fuchen Jia, E.R. Galea, Jun-Ho Choi, Energy and carbon-emission analysis of integrated green-roof photovoltaic systems: probabilistic approach, J. Infrastruct. Syst. 24 (1) (2018) 04017044.