Hotspots and Frontier Analysis of Green Building Research based on CiteSpace

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Abstract. To examine the worldwide progress of green building and identify the areas of research focus and emerging trends over the last ten years, employed CiteSpace software to quantitatively analyze a selection of literature on green building from 2013 to 2023 in the WOS core collection. The key journals, major institutions and countries involved in the study were sorted out, and the research topics of literature high citation analysis were carried out. The research hotspots and frontiers were obtained through keyword co-occurrence, clustering, emergence and timeline analysis: 1) consumption, strategy, thermal performance, emissions are four words of the highest centrality; 2) The five major research topics are new building materials, sustainable development, green innovation, environmental impact, and building information model; 3) The combination of green building and intelligent building is the development trend; 4) Three frontier research directions are green finance, energy simulation and geopolymer concrete. Based on the above analysis, it can be concluded that: 1) Promote the further integration with BIM technology; 2) Sustainable development is still a hot topic; 3) Focus on the exploration of green building materials; 4) AI green buildings will become a trend.

Keywords: Green building, CiteSpace, Bibliometric, WOS, Knowledge graph.

1. Introduction

Green building serves as a crucial solution to address the issues related to buildings and has a significant impact on society, environment, and economy. It acts as an important testament to the coordinated development of people, architecture, nature, and society for over a century [1]. In recent years, China's introduction of the "carbon peak" and "carbon neutrality" goals has led to increased attention from scholars towards green building. As a key approach in reducing energy consumption and carbon emissions, it has gained prominence. The research on green building dates back to 1969 in developed countries of the West and has yielded fruitful outcomes across various fields with diverse perspectives [2]. To aid scholars in understanding its theoretical methods better, identifying existing shortcomings in its development more easily, and providing future research directions, it is essential to employ scientific metrology software for analyzing this field. Therefore, utilizing CiteSpace based on WOS, the knowledge system of green building over the past decade is analyzed. This analysis helps summarize the main characteristics, research hotspots, and developmental trends within this domain through dynamic graphs that depict its macro structure along with prospects.

2. Data Sources and Research Methods

2.1. Data Sources

After selecting data from WOS core collection and conducting several checks, the retrieval formula was set as Topic = (Green buildings* OR Green building* OR Green construction* OR Green constructions*). The retrieval time span was set as "2013-2023", the literature type was set as Article OR Review OR Proceedings Paper, and the language was English. After deduplication, sorting and filtering of the documents retrieved, a total of 12,502 articles were studied, and a visual study was conducted through CiteSpace.

2.2. Research Methods

The visual analysis software CiteSpace used in this paper is a system that can detect and visualize trends and changes in scientific disciplines over time, and it can be used to explore fundamental changes from research frontiers to theoretical foundations. CiteSpace is extensively utilized as a tool for knowledge mapping, effectively illustrating the overall structure of the knowledge domain and its prospective evolution using dynamic graphs that incorporate chronological order. this paper will use CiteSpace to analyze the theoretical structure, evolution process, research hotspot and development trend of green building theme from 2013 to 2023, and carry out multidimensional dynamic network analysis. On the basis of visualization analysis using CiteSpace, the paper also adopts the research method of bibliometrics. It is an interdisciplinary subject that integrates mathematics, philology and statistics to conduct quantitative analysis of knowledge carriers [3]. Taking the system of literature and the quantitative characteristics of literature as the research object, this paper discusses the structural characteristics and development direction of a certain discipline field by analyzing the quantity relationship, distribution structure and change law of literature. Key words timeline map, key words emergence map, etc. are drawn by CiteSpace software, visual analysis of green building research.

3. Literature Feature Analysis

3.1. Document Timing Analysis

Fig. 1 illustrates the time distribution and growth statistics of literature from 2013 to 2023. Over this period, the number of publications steadily increased from 494 to 1736, indicating a rising interest in green building research, highly valued by scholars. This reflects a growing concern for the environmental impact of the construction industry and a scholarly focus on the driving factors in promoting green buildings. The conclusion underscores the significant role of green building in the long-term development of the construction industry, highlighting both new opportunities and challenges due to the proposal of the double carbon target.

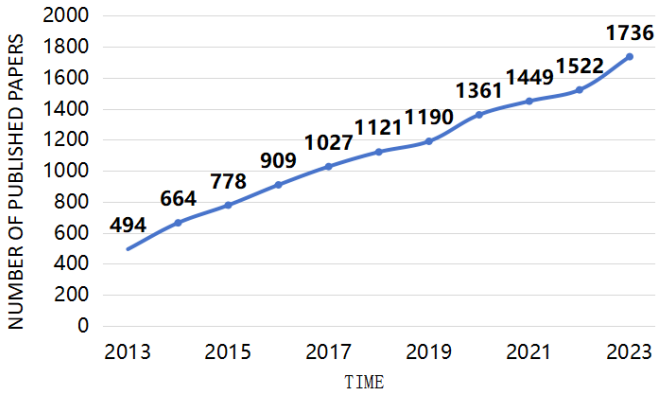

Figure 1. The number and distribution of core journals on green building research from 2013 to 2023

3.2. Analysis of Hot Journals

To identify the key source journals for literature in the green building field, the following compilation of source publications from papers in this area can aid researchers in swiftly grasping the pivotal journals and support them in data collection, paper composition, and submission [4]. In the field of green building research, 12,502 source publications were counted, and Table 1 lists the top ten journals with the highest number of publications. The journal with the most publications from 2013-2023 is SUSTAINABILITY, with an impact factor of 3.9. Among important source journals, the lowest impact factor was only 3.2. However, the impact factor of all 10 journals exceeded 3, indicating a high level of quality of journals related to the field of green building (Table 1).

Table 1. The top 10 journals for publications related to green building research from 2013 to 2023

Rank	Published periodical	Number of Published Papers	Impact Factors for 2022
1	SUSTAINABILITY	730	3.9
2	JOURNAL OF CLEANER PRODUCTION	392	11.1
3	ENERGY AND BUILDINGS	319	6.7
4	BUILDING AND ENVIRONMENT	302	7.4
5	BUILDINGS	182	3.8
6	SUSTAINABLE CITIES AND SOCIETY	162	11.7
7	JOURNAL OF BUILDING ENGINEERING	148	6.4
8	ENERGIES	137	3.2
9	ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH	120	5.8
10	CONSTRUCTION AND BUILDING MATERIALS	107	7.4

3.3. Analysis of Popular Institutions

The cooperative relationship and literature contribution between different institutions in the field of academic research can be revealed through the institutional network relationship [5-7]. By selecting nodes for visual analysis, the network diagram of institutional cooperation is obtained, as shown in Fig. 2. After analysis, research papers in this field include 77 research institutions, and the top ten institutions with the number of published papers are shown in Table 2. From 2013 to 2023, the country with the highest number of publications is China, with 6 of the top 10 institutions in the world belonging to China, indicating that China's status in the field of green building is gradually rising. On the whole, a community centered on Malaysian University of Science and Technology, National University of Singapore, Tongji University and other universities has been formed in the figure, and cooperation among international higher education institutions is relatively common.

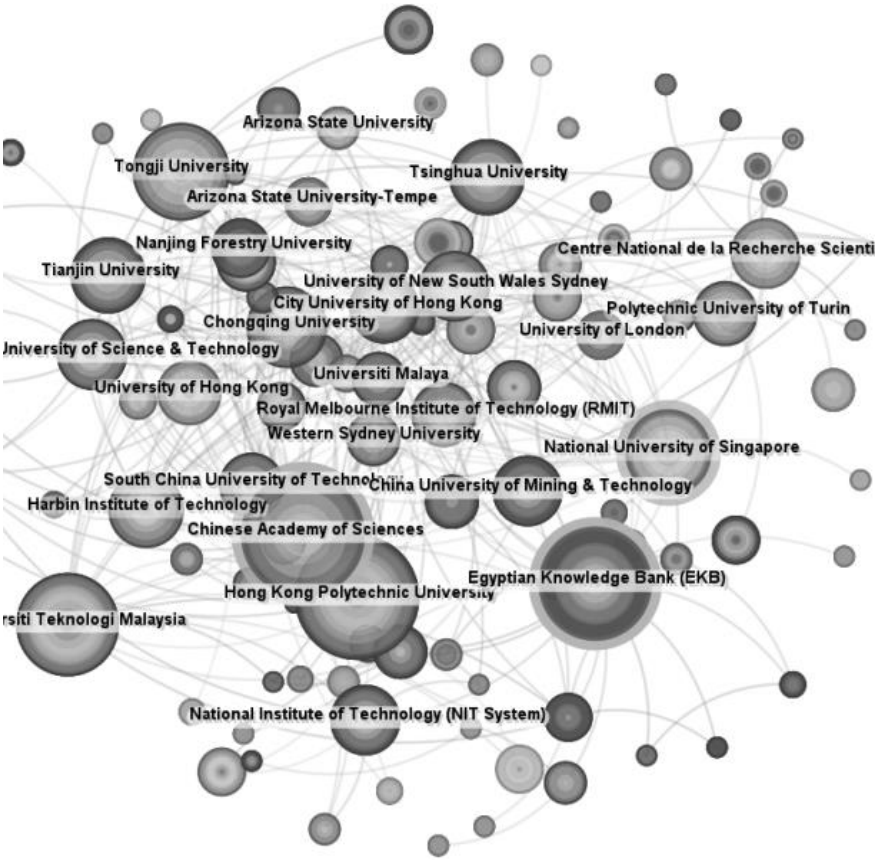

Figure 2. Cooperative Network of Green building institutions 2013-2023

Table 2. The top 10 research institutions in the field of green building research in terms of publication volume from 2013 to 2023

Rank	Institution	Centrality	Nation
1	Hong Kong Polytechnic University	193	China
2	Chinese Academy of Sciences	192	China
3	Egyptian Knowledge Bank (EKB)	168	Egypt
4	Universiti Teknologi Malaysia	139	Malaysia
5	Tongji University	137	China
6	National University of Singapore	123	Singapore
7	Chongqing University	110	China
8	Tsinghua University	105	China
9	Tianjin University	103	China
10	Centre National de la Recherche Scientifique (CNRS)	102	France

4. Research Hotspot Knowledge Graph Analysis based on CiteSpace

4.1. Literature Citation Analysis

Through the analysis of co-cited literatures, highly cited literatures (referring to the references with high citation frequency) can be obtained, which has great significance in the research field. The time line from 2013 to 2023 is divided into 10 time periods in the software, and literatures that are cited at least 4 times are selected to generate a co-cited network, as shown in Fig. 3.

The ten most frequently cited literature for analysis were selected. Please refer to Table 3 for specific details. The highly cited literature topics mainly focus on research related to the obstacles in the development of green buildings, the evaluation system of green buildings, the development trends of green buildings, and the driving forces behind the adoption of green buildings.

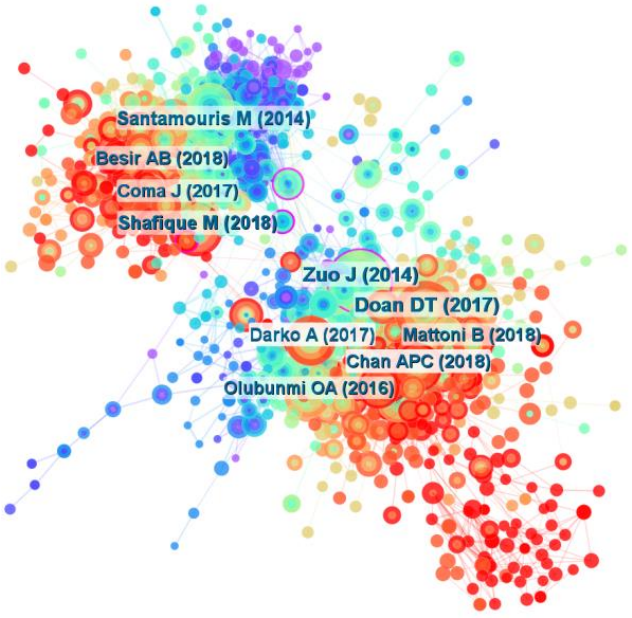

Figure 3. Green building literature co-citation network

Table 3. Ten commonly referenced papers within the field of sustainable construction

No.	Author	Title	Year	Cited frequency	Source
1	Santamouris M	Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments	2014	1008	SOLAR ENERGY
2	Zuo J,Zhao Z Y	Green building research-current status and future agenda: A review	2014	638	RENEWABLE & SUSTAINABLE ENERGY REVIEWS
3	Doan DT	A critical comparison of green building rating systems	2017	306	BUILDING AND ENVIRONMENT
4	Shafique M	Green roof benefits, opportunities and challenges - A review	2018	322	RENEWABLE & SUSTAINABLE ENERGY REVIEWS
5	Besir AB	Green roofs and facades: A comprehensive review	2018	246	RENEWABLE & SUSTAINABLE ENERGY REVIEWS
6	Chan APC	Critical barriers to green building technologies adoption in developing countries: The case of Ghana	2018	241	JOURNAL OF CLEANER PRODUCTION
7	Darko A	Drivers for green building: A review of empirical studies	2017	240	HABITAT INTERNATIONAL
8	Olubunmi OA	Green building incentives: A review	2016	220	RENEWABLE & SUSTAINABLE ENERGY REVIEWS
9	Coma J	Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades	2017	197	BUILDING AND ENVIRONMENT
10	Mattoni B	Critical review and methodological approach to evaluate the differences among international green building rating tools	2018	154	RENEWABLE & SUSTAINABLE ENERGY REVIEWS

4.2. Keyword Co-occurrence Research Hotspot

Key words reflect the theme and central idea of literature, and the core content of green building research can be obtained through the analysis of keywords [8]. Therefore, keywords in the literature from 2011 to 2021 are used as the analysis content. Firstly, the data of WOS is imported into CiteSpace software, and the network node is the keyword. One year is used as the time slice to export the green building keyword network diagram, as shown in Fig. 4. After deleting the names of disciplines and common words such as "construction" (Construction: 149 times; Build: 66 times) and "green building" (Green building: 60 times) from the hot keywords, the export is sorted out as the key research hot spot information table (Table 4).

For the 30 hot keywords listed in the table, "performance" appears the most frequently, followed by "design"; among the keywords with the highest centrality, the three most frequent words are "consumption", "strategy" and "thermal performance", and "emissions", "carbon dioxide" and "urban heat island" also appear frequently. The research focusing on "green building" primarily revolves around four main aspects: energy consumption, design strategy, physical performance, and carbon emissions.

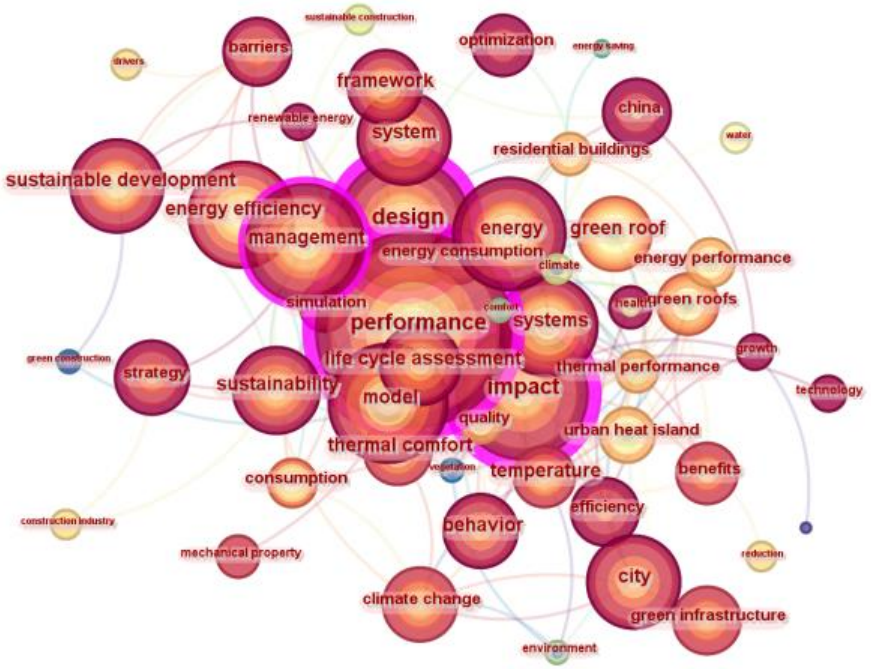

Figure 4. Green building keyword network

Table 4. Key words Research hot information

Rank	Frequency	Centrality	Keyword	Rank	Frequency	Centrality	Keyword
1	286	0.03	consumption	16	282	0.02	barriers
2	269	0.03	strategy	17	258	0.02	quality
3	262	0.03	thermal performance	18	253	0.02	urban heat island
4	187	0.03	emissions	19	246	0.02	energy performance
5	133	0.03	water	20	240	0.02	health
6	92	0.03	building materials	21	233	0.02	optimization
7	82	0.03	embodied energy	22	233	0.02	vegetation
8	63	0.03	building envelope	23	226	0.02	sustainable construction
9	58	0.03	energy use	24	198	0.02	mechanical property
10	39	0.03	carbon dioxide	25	188	0.02	mitigation
11	4	0.03	absorptive capacity	26	174	0.02	growth
12	1378	0.02	performance	27	166	0.02	innovation
13	711	0.02	design	28	165	0.02	ecosystem services
14	315	0.02	thermal comfort	29	158	0.02	concrete
15	305	0.02	behavior	30	146	0.02	office buildings

4.3. Keywords Cluster Analysis

The log-likelihood ratio, which is the default method employed by CiteSpace, is utilized for categorizing keywords and evaluating as well as extracting labels [9]. Distinct clusters indicate diverse domains of knowledge, while identical clusters signify similar research areas. The cluster generated using CiteSpace is shown in Fig. 5. The largest cluster number is 0, and the smallest cluster number is 9. As shown in Table 5, the 9 clusters are listed, and all the contour values are > 8, indicating that the results are significant and reliable.

Table 5. Key words clustering information cluster

Cluster	Keywords
green building	management; sustainable development; barriers
green roof	model; simulation; urban heat island
green innovation	performance; impact; sustainability
LEED	energy; China; life cycle assessment; emissions
green wall	systems; behavior; temperature
green buildings	design; energy efficiency; thermal comfort
compressive strength	mechanical property; concrete; fly ash
extensive green roof	quality; mitigation; water
green infrastructure	climate change; ecosystem services; derivatives

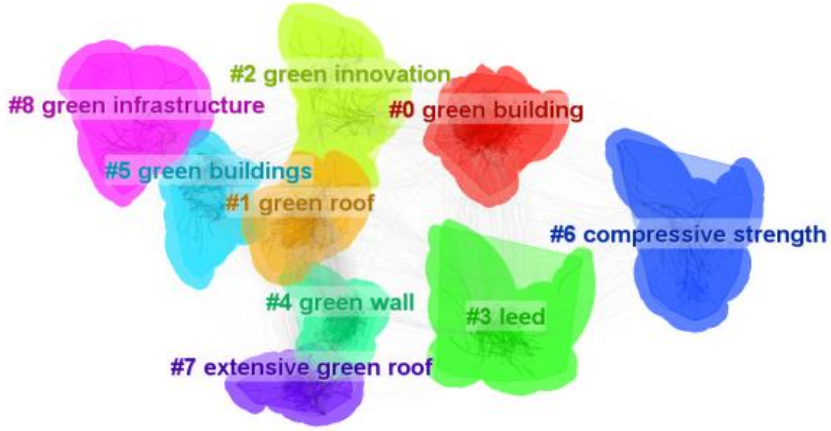

Figure 5. Keywords cluster analysis of green building

4.4. Keywords Timeline Analysis

The keyword timeline map can show the change of research hotspots of green building over time, as shown in Fig. 6. The position of keywords indicates the year when they first appear in the research timeline, and the lines in the map show the relationship between keywords. As can be seen from the map, sustainability, thermal performance, and energy consumption level have always been the focus of research, while comfort, circular economy, and waste treatment have gradually attracted attention in recent years, reflecting the lean and human-oriented nature of green building [10]. With the swift advancement of big data techniques and intelligent algorithms, the integration of smart building and eco-friendly construction will emerge as a prevailing direction.

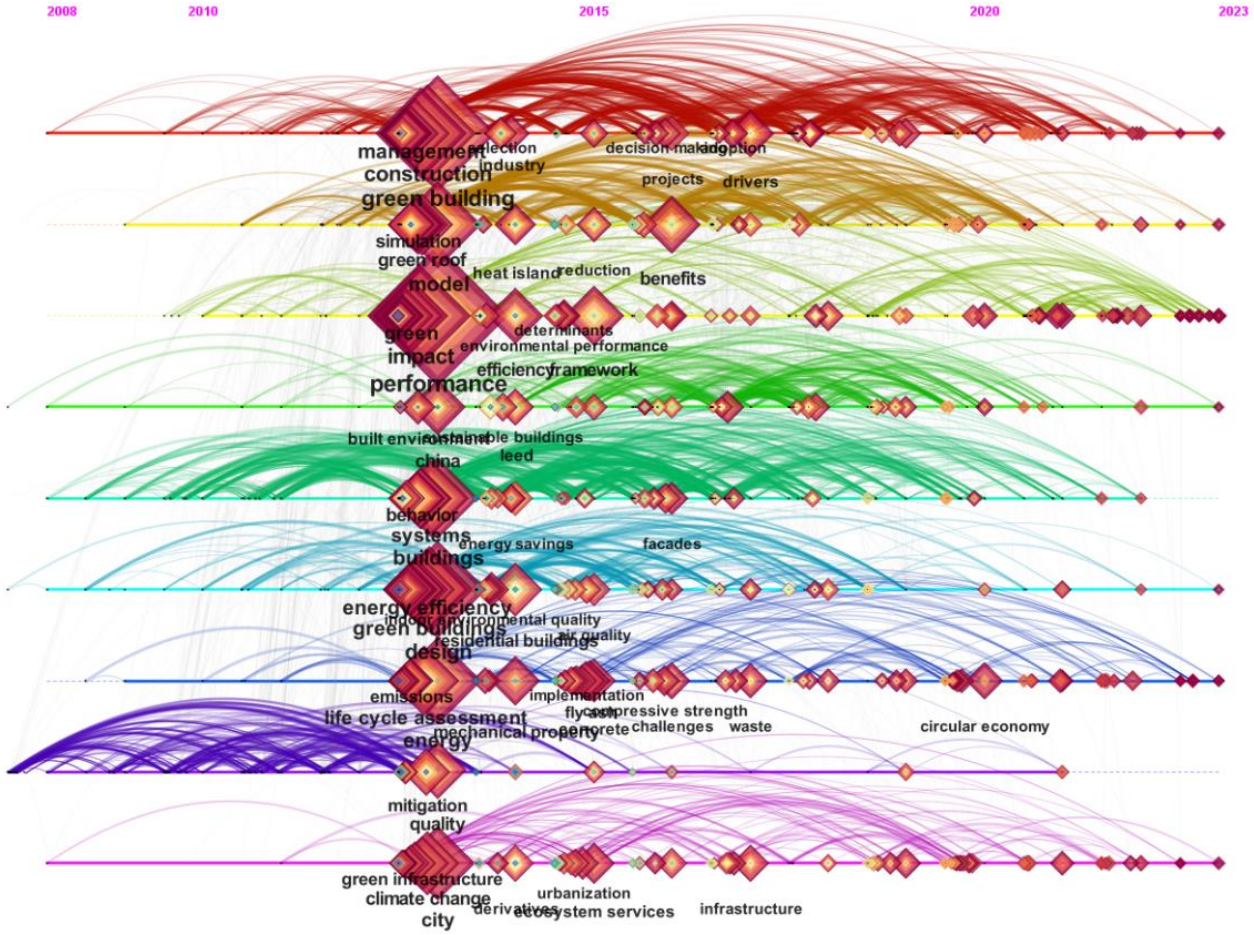

Figure 6. Green building keyword Timeline

4.5. Keywords Emergence Analysis

In the quantitative analysis of written works, it is crucial to identify keywords that exhibit significant bursts. The detection method proposed by Kleinberg J in 2002 is utilized in Citespace for this purpose [11]. Based on the various nodes experiencing bursts, these can be categorized into burst topics, literary pieces, authors, journals, and fields. In Citespace, a cluster containing more burst nodes indicates a higher level of activity or an emerging research trend within the field [11]. By analyzing emergent words, the time distribution of keywords can be explored to detect emergent words with high change frequency and rapid growth, and further explore the frontier fields and research hotspots of this discipline in each period [10]. Citespace is used to analyze emergent words, and the specific information obtained is shown in Table 6.

Table 6. Top 30 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2018 - 2023
water	2018	7	2018	2018	
extensive green roof	2018	5.23	2018	2019	
stormwater management	2018	4.58	2018	2019	
passive cooling	2018	4.45	2018	2020	
urban design	2018	4.08	2018	2019	
rating system	2019	6.13	2019	2020	
retrofit	2019	5.76	2019	2021	
green's function	2019	5.31	2019	2020	
reduction	2018	4.91	2019	2019	
big data	2019	4.13	2019	2020	
technologies adoption	2019	3.99	2019	2019	
valuation	2019	3.99	2019	2019	
system dynamics	2019	3.99	2019	2019	
energy simulation	2019	3.92	2019	2021	
green procurement	2020	4.61	2020	2021	
building simulation	2020	4.61	2020	2021	
plant	2020	4.61	2020	2021	
artificial neural network	2020	3.9	2020	2021	
urban green spaces	2021	5.01	2021	2023	
tropical climate	2021	4.64	2021	2021	
mechanical properties	2021	4.34	2021	2023	
lca	2018	4.14	2021	2021	
heat island	2021	4.12	2021	2021	
conceptual framework	2021	4.12	2021	2021	
green finance	2019	8.22	2022	2023	
machine learning	2019	5.33	2022	2023	
green building materials	2022	5.14	2022	2023	
composites	2021	4.84	2022	2023	
geopolymer concrete	2022	4.02	2022	2023	
recycled aggregate	2022	4.02	2022	2023	

5. Conclusion

Based on an analysis of 12502 articles in the core database, CiteSpace was utilized to examine the existing knowledge system of green building. The findings are as follows: (1) Consumption, strategy, and thermal performance frequently appear together. (2) Cluster analysis of keywords reveals that sustainable development, green building materials, green innovation, environmental impact, and building information modeling (BIM) cover a wide range of research areas within green building. (3) Timeline analysis indicates that future developments in green buildings will be influenced by advancements in new building materials and intelligent buildings. (4) Noteworthy keyword occurrences include "green finance" as the most prominent emerging term, "energy simulation" as the most persistent emerging term, and "geopolymer concrete" and "recycled aggregate" as recent emergent terms. These results suggest that current research interests in the field of green building focus on topics such as green finance and new building materials while also highlighting BIM's sustained popularity over recent years.

Shortcomings and expectations: (1) It is crucial to consider integrating BIM technology with the entire life cycle of green buildings and utilizing energy consumption analysis software collaboratively,

in order to enhance its application during the design and construction phase. (2) The focus on sustainability in green building has primarily been on environmental aspects, neglecting other dimensions such as social sustainability. Therefore, it is essential to expand our attention towards society and economy while still prioritizing environmental sustainability. (3) Currently, there is a limited availability of building materials worldwide that are costly and have low recycling rates. Future research should explore new composite materials and emphasize material recycling efforts. (4) Despite the rapid advancements in big data and intelligent algorithms, there remains insufficient research on combining green building with intelligent building systems or other emerging fields. Further investigation is necessary in this area.

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