Research Hotspots and Tendency of Green Building Based on Bibliometric Analysis

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Abstract. Green building is a research hotspot in the field of Construction Engineering in recent years. This paper is based on 987 articles collected from the web of Science (WOS) core collection database, using Excel as the data statistical tool, the statistical research is carried out from the aspects of time output, hot institutions, hot journals, hot authors; VOSviewer is used to analyze the knowledge graph of hot authors and hot countries and regions, CiteSpace is used to analyze the co-occurrence words and burst words of keywords, and the frontier of international green building research is obtained. The results show that: the research process of green building can be divided into three main stages: initial development, stable development, rapid development; At present, the eight major research topics are green roof, comparative assessment, building health, conventional building material, engineering design, building green, indoor environment quality, low-carbon integrated power grid.

Keywords. Green building, bibliometric analysis, literature review, knowledge graph, vosviewer, citeSpace.

1. Introduction
Green building refers to saving resources, protecting the environment and reducing pollution to the greatest extent during the whole life cycle of a building, and promoting the coordinated development of man, nature, and architecture [1]. Green buildings have a significant effect on promoting the development of a green economy and low-carbon economy [2], which has attracted the attention of domestic and foreign scholars and formed a large number of research results. On the one hand, these research results are limited to some specific fields, and there is little visual bibliometric analysis on green building research. On the other hand, scholars' review and analysis of green buildings is only a qualitative analysis and summary. Bibliometric analysis methods and software such as VOSviewer and CiteSpace can quantitatively analyze the development and evolution of scientific research from an objective perspective. This paper uses the WOS core collection database from 2000 to 2020 as the data source, VOSviewer, CiteSpace, and other software as analysis tools, combined with the bibliometric analysis method, constructs the green building research knowledge graph, and explores the green building research overview and development process.
2. Research Data and Research Methods

2.1. Data Sources
The data of this study are from the core database of the WOS [3]. For scientific and technological text data, all literature information except the text of the WOS is included in the index database. The main reason for selecting the WOS core database for literature retrieval is that the data structure of the WOS is relatively complete, including literature types, authors, journals, keywords, abstracts, research institutions, and references. Engineering, architecture, and information construction are all included in the database, including major journals and conference papers. The information obtained from the WOS is considered to be effective information for this study [3].

2.2. Retrieval Strategy
In WOS core database, the advanced retrieval method was selected to retrieve (TI = (green building * OR low carbon building * or low-carbon building *) AND language: (English) AND literature type: (article)) (data updated to October 12, 2020), time span = 1985-2020, index = SCI-extended, SSCI. A total of 987 effective documents were obtained. The search results are shown in figure 1 below.

![Figure 1. Diagram of retrieval results of green building papers.](image)

2.3. Research Method
VOSviewer is a bibliometric analysis visualization tool jointly developed by Professor van Eck and Ludo Waltman of Leiden University in the Netherlands in 2010 [4]. The main purpose of Vos viewer is to help researchers quickly build a domain knowledge graph [5], evaluate the academic development trend of research topics, and thus explore the hot spots in the research field.

CiteSpace software is a knowledge graph system developed by Professor Chen Chaomei in 2004. By drawing the knowledge graph of the development of science and technology [6], CiteSpace can visually display the information panorama of the scientific knowledge field [7], and identify the key literature, hot research, and frontier direction in the research field of specific disciplines.

3. General Situation of Green Building Research

3.1. Quantitative Time Analysis
Based on the analysis of 987 pieces of literature in the WOS core database, the earliest one is Heerwagen, J [8] published in building research and information, which has been cited 130 times. This
paper makes a statistical analysis of 987 kinds of literature retrieved from 2000~2020 and calculates the growth rate of the number of documents in each year compared with that of the previous year. As shown in figure 2, the bar column and broken line in the figure represent the growth rate of literature quantity and relative quantity from 2000~2020 respectively.

From the perspective of the absolute number of papers published, the number of papers published from 2000~2010 was less than 20 (Exceptions: 21 in 2008 and 28 in 2009); the number of papers published from 2011~2015 was less than 100, more than 20; from 2016~2020, the number of published papers was more than 100. From the perspective of the overall trend of the growth rate, the relative growth rate in 2004 was the highest: 400%; in 2005, the relative growth rate was 140%; the rest were all within 100%. From the perspective of growth rate fluctuation, the relative growth rate fluctuated in a wide range from 2000~2010; from 2011~2015, the relative growth rate gradually stabilized; from 2016~2016, the relative growth rate was stable.

According to the above figure 2, combined with the absolute number and relative growth rate of papers, the development process of international green building research can be divided into three main stages: initial development stage, stable development stage, and rapid development stage. agreeing with Price's description of the rising stage in the literature growth theory, the research in a certain field is just emerging, the number of papers published is small and the growth is unstable [9]. It is concluded that 2000~2010 is in line with the basic of the rising stage, and the year 2000~2010 is divided into the initial development stage of international green building research; the absolute number of literature from 2011~2015 is relatively stable, and the growth rate shows a steady wave dynamic trend in a certain range, and the period 2011~2015 is divided into the stable development stage of international green building research; the number of literature is rising rapidly and maintaining a high level from 2016~2020 Trend: Although the growth rate of literature quantity in 2018 has slightly decreased, the technology for calculating the growth rate at this stage is relatively large, and the growth rate is still significantly improved compared with the previous two stages. 2013~2017 is divided into the rapid development stage of international green building research.

3.2. Analysis of Hot Authors

The collaborations amongst researchers can promote communication and productivity in research communities the number of articles published in authoritative journals, to a certain extent, represents the academic achievements of researchers. According to the statistics of the authors of the WOS core
collection, 2753 authors were recorded. Among them, Darko A (11 articles) and Gou zh (11 articles) were the most published, and the other representative authors were Li BZ (8 articles), Chan APC (7 articles), Hwang BG (7 articles), Lin Br (7 articles), Yin S (7 articles).

Main Researchers Before 2014
Main Researchers After 2018

Figure 3. Diagram of co-authorship analysis of green building.

The VOSviewer software is used to construct the coverage map of international green building researchers, which intuitively shows the annual interval of main authors. Figure 3 shows the node label, connection line, and time color bar. The node size is directly proportional to the number of articles published by the author, that is, the more the number of articles, the greater the number of nodes; for example, the number of articles (11 articles) of Darko A is the largest, so the display node is the largest. The connection strength is expressed by the thickness. The connection thickness is directly proportional to the quoted quantity, that is, the more the number of citations, the stronger the connection strength; for example, the Darko’s article has been cited most times (316 times), and the total connection strength is 25, so it shows that there are many and thick connections.

The rainbow colour column in the VOSviewer mapping file is used. The colour indicates the author's publishing year, purple indicates that the time of publishing is before 2014, red means that the time of publishing is after 2018, and the rest is between 2014 and 2018. For example, Tan Yongtao [10], Liu Guo [11], Lu Weisheng [12] are new star researchers with a large number of papers published after 2019.

3.3. Analysis of Hot Countries and Regions
Statistical analysis of the distribution of 987 articles in WOS shows that China and the USA have more than 200 papers, accounting for 50.41% [(294 + 200) / 987] of the total literature. Among them, 294 articles were published in China, accounting for 29.79%; 200 articles in the USA, accounting for 20.63%; Followed by Australia (90 articles, 9.12%), England (73 articles, 9.40%), Taiwan (38 articles, 6.82%), South Korea (38 articles, 3.85%), Canada (37 articles, 3.50%), Italy (37 articles, 3.50%), Singapore (37 articles, 3.50%), Netherlands (26 articles, 2.634%). The results show that international green building research has been paid enough attention to the world's major economies, but there is still a large space for the cross integration of research in various countries and regions.
Figure 4. Diagram of density visualization of countries analysis of green building.

Using VOSviewer software to build item density visualization of international green building research countries and regions, and visually display the main contributing countries and regions of the number of published papers. Each point in the item density visualization has a colour that indicates the density of items at that point. Using the definition of the rainbow colour scale, the colour range is from purple to green to red. The more the number of items near a point, the higher the weight of adjacent items, the closer the colour of the point to red. An example of the item density visualization is shown in figure 4. For example, Colour indicates the density of countries and regions at that point, China and the USA published more papers, the closer the colour of the point is to red.

3.4. Analysis of Hot Journals
In order to study the main journals more comprehensively, table 1 lists the number and percentage of the journal papers in descending order, the cumulative number of articles published in the journal from 2000 to 2020, as well as the percentage of green building articles, Cite Score, Scimago Journal Ranking (SJR), SNIP, and the Best Quartile. We used CiteScore and SJR from WOS as indicators of publication response. In the top 10 journals, Building and Environment (CiteScore 2019: 8.4, SJR 2019: 1.871, 73 Articles, 7.40%) ranked first in the number of Green Building research publications, followed by Energy and Building (CiteScore 2019: 9.9, SJR: 2.061, 68 articles, 6.89%), Sustainability(CiteScore 2019: 3.01, SJR: 0.549, 67 articles, 6.79%) and Journal of Cleaner Production (CiteScore 2019: 10.9, SJR: 1.886, 61 articles, 6.18%). The papers published in these four journals accounted for 27% of the total papers. In addition, Building Research and Information (CiteScore 2019:6.8, SJR:2019:1.175) and Sustainable Cities and Society (CiteScore 2019:7.5, SJR:2019:1.356) published 31 articles (3.14% of the total 987 articles) on Green Building. Comprehensive research shows that: compared with other articles, Green Building is more easily accepted by these active journals. The 10 most active journals (80% in Best Quartile 1; 20% in Best Quartile 2) published approximately 40.22% of the Green Building articles.

All 10 most active journals have a CiteScore ranging from 2.80 (Indoor and Built Environment) to 11.2 (Renewable Energy). The top journals with a CiteScore > 10 (2/10; 20% of the top journals) published 2.84% of the total number of Green Building-related articles. The top journals with CiteScore 5~10 (5/10; 50% of the top journals) published 20.57% of the total number of Green Building-related articles. The top journals with CiteScore < 5 (3/10; 30% of the top journals) published 9.42% of the total number of Green Building-related articles. In conclusion, when comparing the rate of Green Building-related articles in medium CiteScore journals (CiteScore 5~10) to that of all, Green Building-related articles were relatively intensively published in medium CiteScore journals.
Table 1. Details of the largest 10 Journals of green building.

| Journal                               | Quantity | Proportion (%) | ISSN Number | Cite Score 2019 | SJR 2019 | SNIP 2019 | Best quartile |
|---------------------------------------|----------|----------------|-------------|------------------|----------|-----------|--------------|
| Building and environment              | 73       | 7.40           | 0360-1323   | 8.40             | 1.871    | 2.604     | Q1           |
| Energy and buildings                  | 68       | 6.89           | 0378-7788   | 9.90             | 2.061    | 2.334     | Q1           |
| Sustainability                        | 67       | 6.79           | 2071-1050   | 3.01             | 0.549    | 1.169     | Q1           |
| Journal of cleaner production         | 61       | 6.18           | 0959-6526   | 10.9             | 1.886    | 2.394     | Q1           |
| Building research and information     | 31       | 3.14           | 0961-3218   | 6.80             | 1.175    | 2.167     | Q1           |
| Sustainable cities and society        | 31       | 3.14           | 2210-6715   | 7.50             | 1.356    | 1.987     | Q1           |
| Renewable energy                      | 17       | 1.72           | 0960-1481   | 11.2             | 2.052    | 2.366     | Q1           |
| Energies                              | 14       | 1.42           | 1996-1073   | 3.80             | 0.635    | 1.154     | Q2           |
| Energy policy                         | 12       | 1.22           | 0301-4215   | 8.70             | 2.168    | 1.931     | Q1           |
| Indoor and built environment          | 12       | 1.22           | 1420-326X   | 2.80             | 0.430    | 0.966     | Q2           |

3.5. Analysis of Hot Organization

Table 2 illustrates the five major quantitative measurements of selected scholars who published more than ten articles, including the number of articles, total citations, average publication year, average citations, and normalized citation in the WOS.

Table 2. Details of the largest 13 affiliations of green building.

| Affiliation                          | Number of Total Citations | Average publication year | Average Citations | Ave. Citation | Norm Citation |
|--------------------------------------|---------------------------|--------------------------|-------------------|---------------|---------------|
| The Hong Kong Polytechnic University | 38                        | 2016                     | 27                | 1.63          |
| National University of Singapore     | 31                        | 2017                     | 21                | 1.27          |
| Chongqing University                 | 25                        | 2016                     | 13                | 1.04          |
| Tsinghua University                  | 17                        | 2016                     | 18                | 1.51          |
| Shenzhen University                  | 16                        | 2018                     | 21                | 1.89          |
| Tongji University                    | 16                        | 2016                     | 28                | 1.30          |
| The University Hong Kong             | 16                        | 2017                     | 19                | 1.39          |
| Tianjin University                   | 15                        | 2018                     | 9                 | 0.69          |
| City University of Hong Kong         | 11                        | 2017                     | 22                | 1.52          |
| National Taiwan University           | 11                        | 2015                     | 27                | 1.27          |
| National Taiwan University Science and Technology | 11            | 2016                     | 11                | 0.59          |
| Shanghai Jiao Tong University        | 11                        | 2011                     | 33                | 0.74          |
| University Teknologi Malaysia        | 11                        | 2018                     | 16                | 1.32          |

The first three measures demonstrate the positive impact of research institutions on outputs and research areas. Table 2 shows that the Hong Kong Polytechnic University is the research institution with the highest output (38 articles and 1037 citations) from the selected institutions (13 research institutions with more than 10 articles published). Therefore, Hong Kong Polytechnic University is the most influential research institution in the field of Green Building research. The average publication years of institutions indicate that most institutions have emerged in the past five years. The standardized citation analysis of the organization shows that the average publishing influence of the organization every year. For example, the City University of Hong Kong (11 articles) and University Teknologi Malaysia (11 articles) published relatively few articles, but the standardized citation rate of these research institutions ranked third and sixth respectively. Therefore, the research results of these
research institutions in the field of green building are also worthy of attention. The results show that hot research institutions are mainly concentrated in the Asia Pacific region.

4. Research Progress of Green Building

4.1. Analysis of Research Hotspots

Keywords are the direct embodiment of the subject content of an article and an important index of bibliometric research [7]. By analyzing the keywords in the field of green building research, we can further grasp the research hotspots and evolution trends in this field. Use CiteSpace to cluster keywords and analyze research hotspots.

![Figure 5. Diagram of clustering keywords analysis of green building.](image)

As shown in figure 5, there are 565 nodes and 1021 lines, the network density is 0.0064, the module value of Modularity Q (i.e. M) is 0.8102, and the Mean Silhouette (i.e. S) is 0.5204. Generally, M > 0.3 and S>0.5 indicates that the keyword clustering result is better. The node size represents the frequency of keywords appearing in the article, and the node size is directly proportional to the frequency of keywords. The thicker the line is, the more likely the two keywords appear in the same literature. The network is divided into 20 co-citation clusters. These clusters are labeled by index terms from their own citers. The largest 8 clusters are summarized. Limited to the length of the article, only the first eight clusters are explained. See table 3 for specific analysis.

| Cluster ID | Size | Mean Silhouette (TF-IDF) | Label (LLR) | Mean Active Citer |
|-----------|------|--------------------------|-------------|-------------------|
| 0         | 51   | 0.788                    | Green roofs | 2014              |
| 1         | 38   | 0.807                    | Green buildings | Comparative assessment | 2011 Illankoon, Imcs [14] |
| 2         | 37   | 0.971                    | sustainability | Building health | 2008 Wei, Taibing [15] |
| 3         | 35   | 0.946                    | Gold nanoparticles | Conventional building material | 2014 Cheng, Yu-Hsiang [16] |
| 4         | 34   | 0.884                    | Production | Engineering design | 2012 Ingrao, Carlo [17] |
| 5         | 33   | 0.786                    | Building green | Building green | 2015 Liu, Guo [11] |
| 6         | 33   | 0.964                    | Office buildings | Indoor environment quality | 2010 Pioppi, Benedetta [18] |
| 7         | 33   | 0.840                    | Making mechanisms | Low-carbon integrated power grid | 2015 Xia, Wenfei [19] |
4.2. Analysis of Burst Words

The clustering of emergent words forms a sudden topic, which can be used to detect emerging trends and sudden changes in scientific research [5, 7]. Compared with other traditional knowledge graph software, CiteSpace has better performance in the extraction of paroxysmal words. As shown in figure 6, CiteSpace is used to analyze burst words.

As shown in figure 6, 20 burst words are obtained. Among them, the year is the year when the co-occurrence word first appears; the intensity represents the burst intensity; the start time and end time represent the sudden time period, which indicates that burst word has become a research hotspot in the sudden period. Combined with the analysis of figure 1, we can see that the analysis of sudden co-occurrence words is also divided into three main stages.

In the first stage (Initial Development), Environment (Strength: 4.1592, Begin~ End: 2008 ~2014), Green Building (Strength: 2.9417, Begin~ End:2007 ~2013), the research topics of green building are the deepening and extension of environmental protection research. In the second stage (Stable Development), Impact(Strength: 4.8499, Begin~ End:2013 ~2014), Performance(strength: 3.0160, Begin~ End:2015 ~2016), the period of theoretical deepening of research directions and themes, it shows that the research theme of green building has gradually deepened to specific branches; In the third stage (Rapid Development), Policy (Strength: 3.6201, Begin~ End:2017 ~2020), Framework (strength: 2.8534, Begin~ End:2019 ~2020), the rapid development of research directions and themes makes it clear that the research topic of green building has been extended to the practical application level. Analysis of figure 6 shows that: in the third stage, the intensity of sudden co-occurrence words is significantly lower than that in the first two stages, which is mainly due to the diversification of research topics in the third stage, that is, there are more research hotspots in the third stage. At the same time, it also confirmed that the research paper maintained a high yield level in the third stage.

5. Conclusion

This paper draws the knowledge graph of international green building research from 2000 to 2020 by using the visualization techniques such as VOSViewer and CiteSpace and analyzes the basic situation and research progress of international green building research in recent 20 years.
(1) According to the statistics of published papers and visual analysis of emergent words, the research process of green building can be divided into three main stages. From the analysis of the evolution process of the I–III stages, the research focus of the green building is from the single green building technology and green building construction technology, showing the trend of multi-dimensional cross integration;

(2) From the analysis of statistical data in various aspects, the Asia Pacific region is an important research position for green building research, from which important and high-yield research institutions come; however, from the source of journals, there are few influential top journals in the region. For the comprehensive development of green building research, scholars in the Asia Pacific region should devote themselves to cultivating local journals.

(3) Through the analysis of keywords and research hotspots, burst topic analysis, and keyword co-occurrence network clustering knowledge graph analysis, it is known that green roof, comparative assessment, building health, conventional building material, engineering design, building green, indoor environment quality, low-carbon integrated power grid are the current research hotspots.

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