The state-of-the-art of green building research (2010-2019): A bibliometric review

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Abstract. The construction industry is one of the largest energy consumers and also the largest carbon emitter. Under the background of sustainable development, energy saving and emission reduction in construction industry has become an important task. Green building can save resources and energy, so it has been widely concerned, and many studies on green building have been carried out. To better grasp the latest research progress of green building, this paper conducts a bibliometric review of 1068 research papers related to green building from 2010 to 2019. The results show that the research of green building is on the rise by rear, performance and sustainability are the key research contents, and many countries are actively participating in the research of green building. This paper provides a reference for the progress research of green building.

1. Introduction
In recent years, energy crisis and environmental pollution have become a major problem facing the world. The construction industry is the largest energy consumer, consuming 40% of the world's energy and emitting 30% of the world's greenhouse gases [1]. With the global warming, more and more attention has been paid to building energy conservation in the world. People are increasingly aware that carbon dioxide generated by building energy is the main source of climate warming. Green building has become an inevitable trend of architectural development. Green building refers to the building built on the principle of sustainability, which can save resources and energy, protect the environment and reduce the pollution caused by the building [2]. Nowadays, many countries are actively exploring the energy efficiency of green buildings and formulating a series of green building rating system.

Many scholars have carried out research on green building, including green building rating tools [3, 4], green building performance [5, 6], green building project management [7, 8] and so on. For example, Huo et al. evaluated the effectiveness of five international building rating tools in site planning and design [9]. Wu et al. evaluated the performance of green buildings in reducing carbon emissions from a life cycle perspective [10]. Hwang and Tan investigated the obstacles in green building project management, and put forward the relevant project management framework [7]. In addition, green building technology [11] and green building design [12] are also important research contents. There are many research topics on green building, covering a wide range. In order to further reveal the development law of green building research, it is necessary to systematically analyze the existing research papers.

To intuitively show the latest progress of green building research and dig out the hot topics of research, this paper uses VOSviewer software to make a quantitative analysis of the relevant research on green building from 2010 to 2019 from four aspects: the year of publication, key words, international cooperation relations and journal source. The rest of this paper is as follows: Section 2 introduces the
bibliometric methods used in this paper. Section 3 analyses the bibliometric results. Section 4 gives the conclusion.

2. Methods

2.1. Literature data source
The literature data used in this paper retrieve from the core collection of Web of Science (WoS), and Science Citation Index Expanded (SCI-EXPANDED), Social Science Citation Index (SSCI) were selected. Search with "green building" as the topic, i.e., only papers containing "green building" in the title, abstract or key words are eligible. The time span is set for 2010-2019. As of August 1, 2019, there are 1,068 eligible papers, including 21 highly cited papers and one hot paper.

2.2. Bibliometric index
There are many methods and corresponding indexes in bibliometrics to study the research status of a subject. Citations, co-occurrence, impact factor (IF) and so on are mainly used in this paper. Citations refer to the number of citations of a paper, which can also be summed to obtain the total citations of a journal or a country. Co-occurrence refers to the occurrence of two different keywords, countries or research institutions occurring at the same time in the same paper. IF, the most popular measure of journal quality and impact, is calculated by dividing the total number of citations in the past two years by the number of publications in the past two.

2.3. Bibliometric visualization
In order to visualize the results of bibliometrics, this paper utilized the VOSviewer software, version 1.6.9., it’s a popular bibliometrics software [13]. VOSviewer software package is developed by Eck and Waltman [14], which can be freely downloaded at: http://www.vosviewer.com/. The software can perform visual analysis on such bibliometric indexes as co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation. Results visualized through the network connection graph, the size of the circle represents the relevance of the project, the higher the correlation, the bigger the circle. The thickness of the connecting line indicates the closeness between the two projects, the thicker the connecting line is, the higher the project closeness is. The colors of the circles and wires are used for clustering.

3. Results
In this section, we illustrate the results of this study from four aspects: publication year, keywords, country and journal source.

3.1. Publication year trend
According to statistics, the number of papers on green building published between 2010 and 2019 is 1,068. The distribution of the number of publications with the year is shown in Figure 1. It can be seen that the number of publications shows an overall upward trend with the year. The number of publications in 2012 increased significantly from 2011, reaching 83, almost twice the number in 2011 (42). The number of publications in 2014 exceeded 100 for the first time (112), and declined slightly in 2015. In 2018, the maximum number of publications is 174. As the statistics deadline is August 1, 2019, the number of publications in the whole year of 2019 is incomplete, which is 130 and less than that in 2018 at present. It is expected that the number of publications in the whole year of 2019 will be higher than that in 2018.
Figure 1. Number of publications by year 2010-2019.

3.2. Keywords co-occurrence network
In order to more intuitively analyze the hot topics in green building related research, we conduct statistical analysis of the keywords in the papers. Figure 2 is co-occurrence network of keywords. As can be seen from Figure 2, “green building”, “performance [15]”, “sustainability [16]” and “design [17]” is the main node, indicating that these words are important content of green building related research. Then we further analyze the top 20 keywords, and the frequency and total link strength of these keywords are listed in Table 1.

Table 1. Top 20 Keywords.

| Rank | Keyword      | Freq | TLS  | Rank | Keyword | Freq | TLS  |
|------|--------------|------|------|------|---------|------|------|
| 1    | Green building | 301  | 1362 | 11   | China   | 67   | 402  |
| 2    | Performance  | 156  | 881  | 12   | Model   | 64   | 393  |
According to Table 1, we can see that “green building” appears 301 and have the highest link strength (1362). Followed by “performance” and “sustainability”, the frequency is similar, around 150 times. “Design” and “construction” rank fourth and fifth, respectively, and the frequency is over 100 times. The rest of keywords are used less than 100 times. LEED (Leadership in Energy and Environmental Design) is also a hot topic, as a set of standards [18-20].

### 3.3. Productive countries with green building

Table 2 lists the top 20 productive countries of papers on green building from 2010-2019. It can be seen that China is the country with the highest output, with 374 publications, 4666 citations and 173 total link strength. Followed by USA, the number of publications is 287, and the number of citations is 4415. Australia ranks third, with 90 publications and 162 citations, much fewer than China and USA. England ranks fourth, with publications and citations almost half that of Australia, 52 and 695 respectively. Korea, Singapore, Malaysia and Canada rank fifth to eighth, with publications ranging from 40 to 50.

| Rank | Region         | Freq | Citations | TLS | Region       | Freq | Citations | TLS |
|------|----------------|------|-----------|-----|--------------|------|-----------|-----|
| 1    | China          | 374  | 4666      | 173 | Turkey       | 25   | 222       | 9   |
| 2    | USA            | 287  | 4415      | 90  | Germany      | 18   | 161       | 9   |
| 3    | Australia      | 90   | 1620      | 89  | Spain        | 18   | 275       | 3   |
| 4    | England        | 52   | 695       | 42  | Netherlands  | 17   | 440       | 11  |
| 5    | South Korea    | 47   | 448       | 16  | Japan        | 14   | 181       | 11  |
| 6    | Singapore      | 46   | 947       | 39  | Egypt        | 14   | 79        | 5   |
| 7    | Malaysia       | 46   | 741       | 29  | New Zealand  | 13   | 145       | 7   |
| 8    | Canada         | 40   | 660       | 19  | France       | 12   | 347       | 7   |
| 9    | Italy          | 32   | 493       | 14  | U Arab       | 12   | 156       | 5   |
| 10   | India          | 27   | 335       | 8   | South Africa | 12   | 153       | 2   |

Note. Freq, Frequency; TLS, Total Link Strength.
Figure 3. Cooperation status of the top productive countries.

Figure 3 represents the cooperation status of the top productive countries. As can be seen in Figure 3, China, USA, Canada, South Korea and Malaysia are the main nodes, and the links between China and USA are also very close. In addition, China and Australia, Singapore, the United States and Canada, South Korea are also closely linked.

Take China as the representative, and further analyze its connection with other countries. The cooperation network of China is also shown as Figure 3. As shown in Figure 3, USA, Turkey and Singapore are divided into the green cluster. Italy, Germany and India are divided into the red cluster. Australia, Malaysia, New Zealand Nigeria and Scotland are divided into the blue cluster. Therefore, geographical location is a factor that affects cooperation between China and other countries. Nowadays, with more and more people going abroad to study, academic cooperation between countries is becoming more and more common.

3.4. Productive journals with green building

Table 3 presents the top 15 productive journals with green building. Among them, Sustainability is most published journal related to green building, with 68 publications, followed by Journal of Cleaner Production, and the number of publications is basically the same as Sustainability. Energy and Buildings and Building and Environment rank third and fourth respectively, with 62 and 59 publications, and 1087 and 1082 citations. It is worth mentioning that the number of publications in Renewable & Sustainable Energy Reviews is 38, while the amount of citations is the highest, reaching 1699, which indicates that it has great influence.

| Rank | Journal                          | TP  | Citations | TLS | IF (2018) | IF (5 years) |
|------|----------------------------------|-----|-----------|-----|-----------|-------------|
| 1    | Sustainability                   | 68  | 283       | 329 | 2.592     | 2.801       |
| 2    | Journal of Cleaner Production    | 67  | 798       | 363 | 6.395     | 7.051       |
4. Conclusion

With the enhancement of people's awareness of energy conservation and environmental protection, the sustainable development of buildings has become an important part of public concern. Green buildings have also received the attention of various countries, and related research has become more and more. In order to reveal the research trend of green building, this paper adopts the method of bibliometrics, draws the co-occurrence network by VOSviewer software, and analyses the related research from 2010 to 2019.

According to the analysis results, the research on green building shows an increasing trend in recent years, which indicates that people pay more and more attention to green building. The results of keyword analysis show that green building, performance, sustainability and design are the hot topics of green building research. At the same time, there is a high degree of connection between words, which shows that each topic is interrelated. In addition, many countries have participated in the research of green architecture, of which China and USA are the most representative countries, and have made great contributions to the research of green building. Besides, China and USA have close cooperation with many countries. The results of journal source analysis show that Sustainability, Journal of Cleaner Production, Energy and Buildings, Building and Environment are the most important source journals, and they have great influence. This paper can provide a reference for scholars interested in green building to better understand the research progress.

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