sustainability

MDPI

Review

Research on the Literature of Green Building Based on the Web of Science: A Scientometric Analysis in CiteSpace (2002–2018)

Yingling Shi * and Xinping Liu *

School of Economics and Management, North China Electric Power University, Beijing 102200, China
* Correspondence: 50600633@ncepu.edu.cn (Y.S.); 1182206253@ncepu.edu.cn (X.L.)

Received: 29 May 2019; Accepted: 4 July 2019; Published: 7 July 2019

check for updates

Abstract: Since the 21st century, the concept of green building has been gradually popularized and implemented in more countries, which has become a popular direction in the area of sustainability in the building industry. Over the past few decades, many scholars and experts have done extensive research on green building. The purpose of this paper is to systematically analyze and visualize the status quo of green building. Therefore, based on Web of Science (WoS), this paper analyzed the existing knowledge system of green building using CiteSpace, identified keywords related to green building and their frequency of occurrence using the function of keyword co-occurrence analysis, recognized five clusters using the function of cluster analysis, and explored the knowledge evolution pattern of green building using citation bursts analysis in order to reveal how research related to green building has evolved over time. On the basis of aforementioned keywords, clusters, and citation bursts analysis, this paper has built a knowledge graph for green building. This paper can help readers to better understand the status quo and development trend of green building and to easier recognize the shortcomings in the development of green building, so as to provide a promising direction for future research.

Keywords: literature review; WoS; green building; visualized analysis; CiteSpace

1. Introduction

With the rapid development of the economy and society, the shortage of energy and the deterioration of environment have become two major problems faced by human beings in today's society. At present, the building industry is the leading source of consumption of world energy sources and various kinds of resources like ores, wood, and so on, as well as the major source of environmental pollution [1]. According to the United Nations Environment Programme (UNEP), energy consumption in the building industry accounts for about 30–40% of the world's energy consumption [2]. China's energy consumption is among the highest in the whole world, and the consumption of the building industry accounts for 38% of the total social energy consumption [3]. Faced with a grim situation, the transformation and upgrading of the building industry is imminent. However, it is difficult for the industry to figure out a green, environmentally friendly, and sustainable road for development. Therefore, there is a crying need for exploring and establishing the sustainable development mode of the building industry in order to transform the current situation of high resource consumption and high environmental pollution.

The report of *Our Common Future*, issued by the World Commission on Environment and Development (WCED) in 1987 [4], formally put forward sustainable development strategies. The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, proposed *the Rio Declaration on Environment and Development* and *Agenda 21* [5]. The agenda provides a separate section on promoting sustainable human settlement development in Chapter 7, focusing on improving settlement planning and management, providing integrated environmental infrastructure, and achieving sustainable settlement development for energy and transport systems. This is the embodiment of the concept of sustainable development in the field of buildings, as well as the concrete realization of green building [6]. Henceforth, green building has been gradually popularized and implemented in an increasing number of countries, and has become the main direction of the development of the building industry in the world. Owing to different conditions in every country such as economic development level, geographical location, and per capita resources, the concept of green building has not reached a consensus yet in the international community. The United States Environmental Protection Agency (USEPA) defines green building as environmentally responsible and resource-efficient building throughout its life-cycle from siting to design, construction, operation, maintenance, and deconstruction [7]. Building Services Research and Information Association (BSRIA) considers that the creation and management of a healthy building environment should be based on the principles of high-efficient resource utilization and ecological benefits [8]. The Building Energy Efficient Research, University of Hong Kong defines that the environmental design of green building is the overall design of buildings; all resources should be taken into consideration for sustainable buildings, including materials, fuels, or users themselves; green building involves many problems and contradictions that need to be solved and every part of design will have an impact on the environment [9]. According to the national conditions of China and the concept of sustainable development, the Ministry of Housing and Urban-Rural Development issued *Assessment Standard for Green Building* on 1 June 2006, and made a definition as follows: Green building refers to maximizing the resources conservation including energy, land, water, materials, and so on; protecting the environment and reduce pollution; providing healthy, applicable, and efficient living room for people; and coexisting harmoniously with nature in the life-cycle of the building [10]. Although different countries have different interpretations for green building, they all agree with the three themes of green building, namely, the effective utilization of resources, the creation of a healthy and comfortable living environment, and harmonious living with the environment. These themes also provide a standard for the development of green building all over the world.

Over the past few decades, scholars have increasingly focused on the research on green building [11], and have issued an increasing number of papers [12]. This may make it tough to grasp the research focus and status quo from thousands of papers, posing a major risk of neglecting essential questions and areas for research and practice improvement [13]. In order to solve this problem, it is necessary to analyze this field by utilizing scientometric software [14]. A literature review is considered to be an effective way to deeply understand the field of research [15]. By systematically combing the existing research, we can figure out the current research situation and development trend of the field, thus providing a direction for future research [15]. It should be pointed out that the development of knowledge is a dynamic process. As scientific literature is constantly updated, we may not have enough time or effort to track it only by relying on non-visualization technology. With the development of science and technology, many visualization tools have emerged in recent years, such as VOSviewer, CoPalRed, Bibexcel, Sci2, VantagePoint, and CiteSpace. All of these tools support document co-citation analysis and keyword co-occurrence analysis, which can help us conduct quantitative and objective analysis of the relevant fields, and reveal the quantitative relations among various studies. For example, Li et al. carried out document co-citation analysis and cluster analysis on the relevant literature from 2004 to 2015 via CiteSpace, and quantitatively proposed the building information modeling (BIM) knowledge graph [16]. On the basis of the Web of Science (WoS) databases, Jiang et al. figured out the research emphasis and development trend of urban planning for climate change from 1990 to 2016 through cluster analysis and knowledge evolution analysis using CiteSpace [17]. Zhao et al. analyzed the characteristics and trends of the new energy vehicle reliability based on literature from 1998 to 2017 using CiteSpace [18]. Chen et al. analyzed 3875 articles related to regenerative medicine from 2000 to 2011 using CiteSpace, finding emerging trends in this area [19].

With the rapid development of computing technology and information visualization technology, scholars can discover the hidden relations and trends in the relevant literature. For example, document co-citation analysis, which searches for relations among documents, has been used by many scholars to draw and create research knowledge structures. The combination of quantification and visualization can help us to further understand the knowledge in the specific area.

CiteSpace is a diverse, time-sharing, and dynamic analysis software for visualizing citations with the development of scientometrics, as well as data and information visualization technologies, aiming at analyzing the underlying knowledge contained in scientific literature [14]. Visualized analysis can promote analytical reasoning by setting visual interaction. As the structure, rules, and distribution of scientific knowledge are presented by means of visualization, the generated visualized graphics are also referred to as "mapping knowledge domains" [20]. CiteSpace effectively helps readers to better understand the areas of research in which they are engaged. It can not only show the whole situation of a certain research field, but also highlight some important documents in the development of the field [21]. It has been launched tens of thousands of times in at least 60 countries, and has been continuously upgraded and updated with high reliability, making it a new tool widely used in scientometrics [22].

2. Research Method

This paper summarizes the existing research on green building based on the literature from 2002 to 2018 in WoS using CiteSpace. This paper can help readers to systematically understand the co-citation documents, key clusters, and keywords, as well as the knowledge evolution pattern of green building from the related literature. Although there is no detailed analysis of all literature related to green building, this paper quantitatively summarizes the status quo and development trend of green building in view of its high reference value of the sample literature.

The contents of this study include the following:

(1) Using the functions of document co-citation analysis, cluster analysis, and keyword co-occurrence analysis of CiteSpace, this paper analyzes the literature of green building from 2002 to 2018, to obtain the knowledge base and knowledge domain of green building;

(2) Identifying the knowledge evolution pattern of green building using citation burst detection;

(3) On the basis of the knowledge base (which consists of keywords related to the research topic), knowledge domain (which is related to key research fields of the research topic), and knowledge evolution (which is an evolutionary process reflected by references with citation bursts), a knowledge graph for green building is built.

2.1. Data Collection

Two keywords, green building and sustainable building, are used for retrieval in different databases, and the number of collected documents is shown as follows: 15,800 in Google Scholar, 7962 in Scopus, 7201 in Springer, 6759 in EI, and 3758 in WoS. The data analyzed by CiteSpace are based on WoS data, and the data collected by other databases must be converted into the data format of WoS before being analyzed. Some data may be incompatible in the conversion process and have an impact on the following analysis [14]. Besides, each record for a document in the CiteSpace has a fixed format, while the document data fields of other databases may be incomplete, increasing the noise of the source data. However, WoS fully covers the most important and influential academic research achievements in the world, and has been widely applied in the past review research [23], with great reference value. In this paper, WoS is selected as the data collection platform under overall consideration, according to the data source needed by CiteSpace.

In this paper, these two keywords, green building and sustainable building, are selected using subject search. The core database and the extended database of bibliographic records are retrieved from WoS. Studies of Hou et al. [24] and Chen et al. [25] show that the knowledge base and knowledge domain of green building can be identified based on the core database, and the knowledge evolution pattern of green building can be identified based on the extended database.

Each bibliographic record of WoS contains the basic information of the article, including the author, title, abstract, keywords, and references, among others. Likewise, each retrieved reference includes the name of the first author, year of publication, source type, issue number, volume number, and DOI.

As the literature related to green building included in the WoS started from 2002, the search time of this article is set from 2002 to 2018. It is shown that there are 3147 documents in the WoS core database and 3758 documents in the extended database. The number of documents of each year is shown in Figure 1.

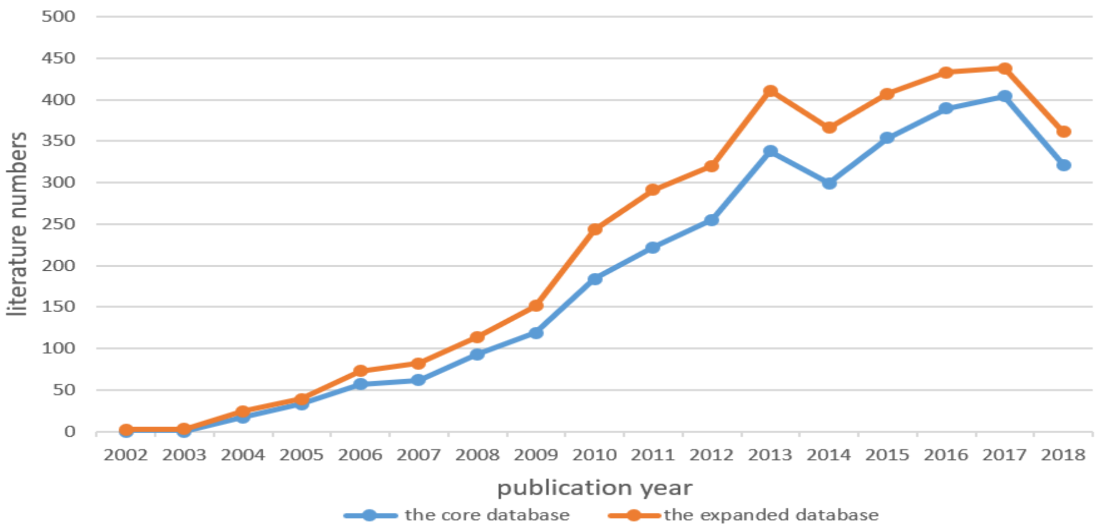


Figure 1. The number of documents from 2002 to 2018.

Figure 1 shows that the number of documents increased year by year from 2002 to 2018, and the trends of core database and extended database are almost the same. Specifically speaking, the number of documents has maintained a rapid increase before 2013, while the number of those that published in the past five years has stabilized at more than 300. It can be seen that research on green building has entered a steady-growth stage, and people's attention to green building also remains at a relatively stable level.

2.2. Data Analysis

The bibliographic map of green building can be illustrated by various kinds of networks such as co-authors, co-cited documents, co-occurrence keywords, and so on, which can be built by CiteSpace. In this paper, we mainly analyze the following aspects including document co-citation network, clustering network, keyword co-occurrence network, and knowledge evolution pattern of green building.

Highly cited documents can be obtained by document co-citation analysis. They refer to the relatively frequent-cited documents in the field of research, which are generally considered to be fundamentally important references to the research. If there are two documents often being co-cited, they may relate to a similar concept. By clusters of statistics, a group of closely related documents can be identified and then aggregated into clusters according to their interconnectivities. Each cluster represents a different knowledge domain, and the same cluster represents the same research domain. Furthermore, the interactions of clusters can reflect their correlation [14]. Keyword co-occurrence network is used to detect keywords that appear in at least two different documents within a time period [19]. As pivotal hotspots in corresponding time periods, these high-frequency keywords and central keywords can be regarded as part of the knowledge base of green building. At present, the knowledge base and knowledge domain of green building are of great importance in conducting research. It is also helpful to recognize references with strong citation bursts using CiteSpace [26]. If one article is frequently cited in a certain time period, the article will be recognized as a reference with strong citation bursts, as well as a milestone paper in the development of the green building discipline. The nodes of strong bursts signify that these documents have received special attention in the corresponding time periods, which can show the frontiers and hotspots of the discipline to a certain extent [19].

3. Results of Citation Analysis

3.1. Knowledge Domain in the Core Database

3.1.1. Document Co-Citation Analysis

On the basis of the visualized analysis of 3147 documents in the core database with CiteSpace, we can obtain a co-citation network of 1693 nodes and 62,565 links. In the network, nodes represent the cited situation of documents in the core database, and links represent the co-citation relations between one node and another [27]. The larger the node, the higher frequency of citation of the document, indicating that the document is of great importance in the green building discipline. The timeline from 2002 to 2018 will be sliced into a series of time periods by CiteSpace, with every two years in each slice. The top 50 documents with the highest frequency of citation in each time period are selected for co-citation analysis, and then a co-citation network is generated. The top 10 frequent co-cited documents from the network are chosen for the further analysis.

Figure 2 shows the top 10 frequent co-cited documents from 2002 to 2018, and the details are shown in Table 1.

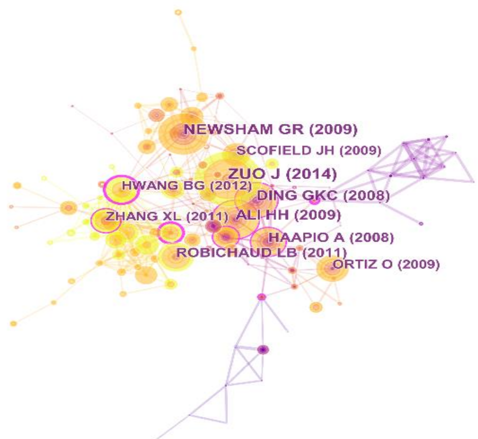


Figure 2. Document co-citation network of green building.

Table 1. Top 10 frequent co-cited documents in the green building discipline.

Author	Title	Year	Freq.	Source
Zuo, J.; Zhao, Z.-Y.	Green Building Research—Current Status and Future Agenda: A Review [15]	2014	79	Renewable and Sustainable Energy Reviews
Newsham, G. R.; Mancini, S.; Birt, B. J.	Do LEED-Certified Buildings Save Energy? Yes, But... [28]	2009	61	Energy and Buildings
Ali, H. H.; Al Nsairat, S. F.	Developing a Green Building Assessment Tool for Developing Countries—Case of Jordan [29]	2009	57	Building and Environment
Ding, G. K.	Sustainable Construction—The Role of Environmental Assessment Tools [30]	2008	52	Journal of Environmental Management
Haapio, A.; Viitaniemi, P.	A Critical Review of Building Environmental Assessment Tools [31]	2008	43	Environmental Impact Assessment Review

Table 1. *Cont.*

Author	Title	Year	Freq.	Source
Robichaud, L. B.; Anantatmula, V. S.	Greening Project Management Practices for Sustainable Construction [32]	2011	43	Journal of Management in Engineering
Ortiz, O.; Castells, F.; Sonnemann, G.	Sustainability in the Construction Industry: A Review of Recent Developments Based on LCA [33]	2009	40	Construction and Building Materials
Hwang, B. G.; Tan, J. S.	Green Building Project Management: Obstacles and Solutions for Sustainable Development [34]	2012	40	Sustainable Development
Zhang, X.; Platten, A.; Shen, L.	Green Property Development Practice in China: Costs and Barriers [35]	2011	39	Building and Environment
Scofield, J. H.	Do LEED-Certified Buildings Save Energy? Not Really [36]	2009	36	Energy and Buildings

Zuo and Zhao summarized the existing knowledge system of green building and figured out that the existing research mainly focuses on the environmental aspect of green buildings; however, the other dimensions of sustainability such as social sustainability and cultural sustainability are neglected to a large extent [15]. Newsham et al. analyzed the energy data of 100 LEED-certified buildings provided by the New Buildings Institute (NBI) and the United States Green Building Council (USGBC). LEED-certified buildings use 18%–39% less energy (per floor) than that of buildings of the same type in average, whereas 28%–35% of LEED-certified buildings consume more energy than that of buildings of the same type, indicating that there is no correlation between the energy performance and the level of certification of the LEED-certified buildings [28]. On the basis of the study of Newsham et al., Scofield made a further analysis of energy conservation of LEED-certified buildings and found that these buildings can have better performance in saving energy when considering the source of energy [36].

With the development of green building, the assessment tools for green buildings have become increasing essential. Ali and Al Nsairat analyzed the international assessment tools for green buildings such as LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), and GB Tool (Green Building Tool), and created a green building assessment tool for developing countries in the case study of Jordan [29]. Ding [30] and Haapio and Viitaniemi [31] conducted critical reviews of existing environmental assessment tools, and discussed the differences and analyzed the current status, validity, and availability of these tools. Ortiz et al. summarized the recent developments of life-cycle assessment (LCA) in the construction industry from 2000 to 2007, and concluded that LCA is critical to the sustainability of buildings [33].

The popularization of green building also faces certain challenges. Robichaud and Anantatmula analyzed green building from two aspects of construction cost and development trend, and figured out the existing difficulties (e.g., the ability of a contractor to handover greening projects under acceptable cost constraints) in the constantly expanding green building market, and proposed detailed modifications to greening project management practices [32]. Hwang and Tan summarized the research progress in the field of green building in recent years, analyzed the energy consumption of green building projects and its impact on the natural environment, called on the whole society to take necessary measures, and promoted the sustainable development of green building [34]. Zhang et al. discussed the costs and barriers of applying green technology to green property development practice in China. By analyzing the additional cost of green buildings, it was concluded that the main barrier to promoting green technology in China is the high cost [35].

3.1.2. Cluster Identification and Analysis (Knowledge Domain)

Identifying highly cited documents by document co-citation analysis is the first step in building a knowledge domain, and the second step is to analyze documents so as to figure out the key research domain. A cluster label is selected from the noun phrases of each cluster. The noun phrases are extracted from the title, keywords, and abstract of documents, and the top-ranked phrases will be likely to be chosen as cluster labels.

CiteSpace provides three different types of cluster labeling extraction algorithms, including log-likelihood ratio (LLR) test, term frequency-inverse document frequency (TF IDF) and mutual information (MI) test. In this paper, LLR test, the default algorithm of CiteSpace, was used to extract the cluster labels. In statistics, a likelihood ratio test is a statistical test used for comparing the goodness of fit of two statistical models—a null model against an alternative model. The test is based on the likelihood ratio, which expresses how many times more likely the data are under one model than the other. This likelihood ratio, or equivalently its logarithm, can then be used to compute a p-value, or compared to a critical value to decide whether or not to reject the null model [37].

Figure 3 illustrates the clusters generated by CiteSpace. The number of the largest cluster is No. 0, and the number of the smallest one is No. 4. The size of a cluster depends on the total number of published papers that the cluster contains.

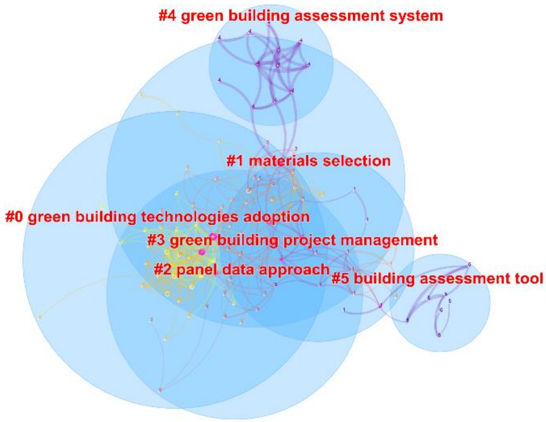


Figure 3. Clusters of knowledge domain within green building.

The analysis results of the clusters are derived from CiteSpace and the largest five clusters are listed. As shown specifically in Table 2, the silhouette value of each cluster is more than 0.65, indicating that the results are robust and meaningful.

Table 2. Top-ranked clusters and the terms within the clusters. LLR—log-likelihood ratio.

No.	Size	Silhouette	Mean (Cited Year)	Label(LLR)(p-value)
0	32	0.872	2013	Green building technologies adoption (405.88, 1.0×10^{-4})
1	24	0.665	2008	Materials selection (287.96, 1.0×10^{-4})
2	20	0.796	2010	Panel data approach (359.76, 1.0×10^{-4}
3	14	0.806	2008	Green building project management (301.88, 1.0×10^{-4})
4	12	0.976	2005	Green building assessment system (272.98, 1.0×10^{-4})
	7	0.981	2004	Building assessment tool (51.81, 1.0×10^{-4})

The largest cluster is the green building technologies adoption, including 32 articles. Green building technologies have three types of goals, namely environmental goal, economic goal, and social goal [38]. In accordance with those goals of green building, China divides the green building technologies into following categories: land conservation and outdoor environment quality management, energy conservation and utilization, material conservation and utilization, water conservation and utilization, indoor environment quality, operation management, and construction management of green buildings [39]. The adoption of green building technologies should take into consideration many factors including construction climate, resources, technical maturity, and economic and social sustainability. Thus, it is necessary to adopt green building technologies with high cost-effectiveness and technical maturity, as well as a great adaption to local resources, environment, and culture. At present, the most prevalent and popular green technologies include thermal bridge blocking technology, green roofing technology, residential ecological ventilation technology, and efficient door and window systems and construction techniques, among others.

The second largest cluster is related to materials selection of green building, including 24 articles. For a long time, the high energy consumption, heavy pollution, and low efficiency of traditional building materials have brought severe problems to the construction market, environmental protection, and healthy life of human beings. Nowadays, green and environmentally friendly materials have taken a leading place in the construction market. It is an inevitable trend to promote and apply green building materials. At the 1st International Conference on Materials Science in 1988, the concept of “green building materials” was first proposed [40]. Green building materials refer to healthy, environmentally friendly, and secure building materials, which are also called “healthy building materials” or “environmentally friendly building materials” in the international community. It is not only the materials that should be green and safe, but also a comprehensive evaluation of health, environmental protection, and safety of building materials in the five procedures of raw materials, production, construction, utilization, and waste disposal. Meanwhile, green building materials are also closely related to architectural design, structure, resources, and policies. Therefore, green building materials are a comprehensive and systematic concept [41]. At present, a series of building systems themed in green building materials has been carried out all over the world, for example, green buildings, ecological buildings, and energy saving buildings, which can be spread to all aspects of the construction industry. The new building materials widely used in the construction process mainly include ecological cement; green glass with functions of high thermal insulation, sound insulation, and heat preservation; and green wall materials made from fly ash, slag ash, and concrete hollow blocks.

The third largest cluster is the panel data approach, including 20 articles. Panel data refer to the sample data formed by selecting sample observed values simultaneously from multiple cross sections in time series [42]. The time series data selected in this way contain three-dimensional information of cross-sectional, time, and index information [43]. The generated model can construct and test green buildings in a more realistic way with better performance simulation and application; therefore, it is widely used in the process of certifying and assessing green buildings. By applying panel data to the analysis of energy consumption characteristics of various resources in the construction industry, some scholars also found that the consumption tendency of different resources and the change of resource consumption caused by other factors can be obtained [44].

The fourth largest cluster is the green building project management, including 14 articles. The main purpose of green building project management is to promote the sustainable development of green building through a systematic management process and reasonable resource allocation [45]. In terms of management, green building project management holds both regional and global horizons. As for the object of management, it has many stakeholders such as landholders, property developers, and urban planners. At present, there are many difficulties in green building project management, such as the imbalance between functions and economical efficiencies, unmixed interdisciplinary technologies, long construction periods, and separated construction processes. It is necessary to take the green construction concepts of energy saving, land saving, water saving, material saving, and environmental protection as the main starting points, and use the virtual partnering mode in project management (On the basis of the common interests, partnering mode refers to establish a mode with shared relations, shared objectives, shared benefits, and shared risks in the construction process to achieve the goal of maximizing the interests of all parties [46]). In a word, green building project management follows the rules of green economy and promotes the development of green building by means of resource saving and environmental protection [47]. It is found that green building project management based on BIM technology still needs further research.

Other major clusters are the green building assessment system and the building assessment tool, including 12 articles and 7 articles, respectively. These two clusters deal with the same aspects of green building assessment of green buildings, just considering the differences in expression by different scholars. Therefore, they should be within one cluster. At present, the international assessment systems of green buildings mainly include LEED [48], BREEAM [49], CASBEE (Comprehensive Assessment System for Built Environment Efficiency) [26], HQE (High Quality Environmental) [50], GB Tool [51], and Assessment Standard for Green Building [52]. The structure of these assessment systems is quite similar to a large extent, covering all aspects of sustainable development. It is worth noting that the green building assessment system in each country is constructed according to the local climatic conditions and local needs, so that the assessment criteria are not the same. There are also some scholars managing to develop new assessment tools for green buildings to better adapt to local climate and geographical conditions. For example, borrowed from the mature assessment systems for green buildings such as LEED, BREEAM, and GB Tool, Ali and Al Nsairat developed the green building rating system for Jordan with greater emphasis on social and economic sustainability according to the specific conditions of the country [29]. At the same time, the constant updates of green building assessment systems reflect that the direction of green building assessment is changing according to the social and cultural aspects of sustainable development.

3.1.3. Keyword Co-Occurrence Network (Knowledge Base)

Because of the close relation between the keywords and the cores of documents, the analysis of similar keywords can help to identify the cores of green building research. The terms are being grouped hereinafter, for example, green building, sustainable building, and sustainable construction can be divided into one category. Figure 4 is a keyword co-occurrence network of 309 nodes and 1469 links generated from the core database, where nodes represent the keywords. It can be seen that the font size of keywords is proportional to the co-occurrence frequency of the keywords [20].

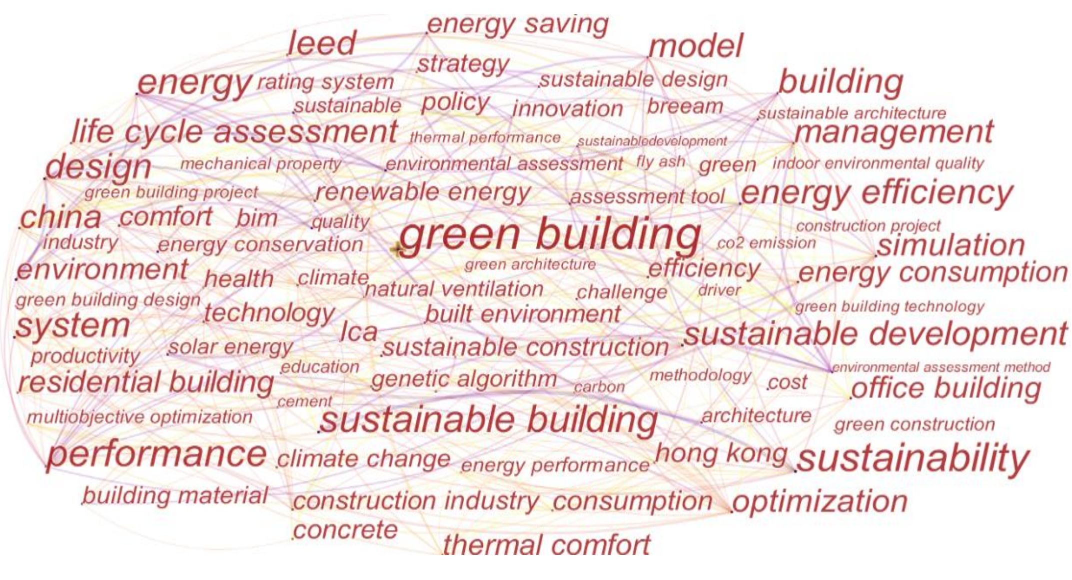


Figure 4. Keywords co-occurrence network.

Table 3 lists the top 60 keywords in green building according to the co-occurrence frequency, with a cumulative co-occurrence frequency of 5348, accounting for more than 88% of total frequencies (5348/6040).

Table 3. Top keywords with their frequencies in green building. BIM—building information modeling.

No.	Keywords	Freq.	No.	Keywords	Freq.
1	green building/sustainable building/sustainable construction	1050	31	technology	35
2	sustainability/sustainable development/green/sustainable	445	32	construction industry	35
3	construction/building	310	33	perspective	34
4	performance/energy performance	256	34	life cycle	32
5	energy/renewable energy/solar energy	222	35	health	30
6	LEED/BREEAM/rating system/assessment tool	198	36	BIM (Building Information Modeling)	30
7	model/simulation	197	37	framework	28
8	design/sustainable design	175	38	strategy	27
9	system	160	38	natural ventilation	24
10	China/USA/Hong Kong	76/51/33	40	innovation	23
11	life cycle assessment (LCA)	156	41	industry	22
12	residential building/office building	149	42	genetic algorithm	20
13	energy efficiency	137	43	selection	20
14	impact/environmental impact	115	44	driver	17
15	management	108	45	quality	17
16	energy consumption	106	46	fly ash	16
17	environment/built environment	104	47	environmental assessment method	15
18	thermal comfort/comfort	99	48	risk	14
19	optimization	85	49	Indoor environmental quality	13
20	barrier/challenge	60	50	mechanical property	13
21	energy saving/energy conservation	60	51	education	12
22	concrete/cement	59	52	architecture	12
23	(green) building material	55	53	green building design	11
24	climate change/climate	52	54	embodied energy	11
25	emission	46	55	cost	11
26	project	46	56	environmental performance	11
27	consumption	46	57	waste	10
28	efficiency/productivity	45	58	recycling	10
29	behavior	40	59	green building project	9
30	policy	36	60	thermal performance	9

As seen from the co-occurrence frequency in Table 3, the most frequently used keywords are the following: green building/sustainable building/sustainable construction (1050 times), sustainability/sustainable development/green/sustainable (445 times), construction/building (310 times); performance/energy performance (256 times), energy/renewable energy/solar energy (222 times), and LEED/BREEAM/rating system/assessment tool (198 times). Therefore, it can be considered that energy performance, energy type, and green building assessment tools are the basic components of the green building knowledge system.

Modeling and simulation are important research key points with a co-occurrence frequency of 197 times. Green building has considerable connotations and should be managed with the help of modern information technology. Building information modeling (BIM) technology can replace the traditional two-dimensional drawings with the three-dimensional visualized model, improves the design efficiency and the quality of drawing review, and can find errors in the construction drawings more quickly and correctly in time. At the same time, it can simulate every construction process in advance through the three-dimensional model, which will optimize the construction procedures and facilitate communication with all parties of the project [53]. Modeling and simulation are needed throughout the life-cycle of the building from design to construction, and operation [54]. As a new method in the construction industry, the continuous improvements and perfections of BIM technology bring unprecedented opportunities and challenges to the development of the construction industry in China. At present, the technology is widely used in some western developed countries, but not too much in China. Although some studies have already carried this out, the application of BIM to every stage of the life-cycle still requires a great deal of analysis and argumentation. China still has a long way to go to make achievements.

Design (sustainable design) is also an important research focus of green building with a co-occurrence frequency of 175 times. Ensuring the health of residents is the priority of green building design. It should be aware of reducing impacts on the natural environment and designing energy conservation buildings that meet the principles of system synergy, territoriality, high efficiency, nature protection, health, economy, and evolution [55]. Some scholars argue that both economic and environmental benefits should be taken into consideration in designing green buildings. Now, the construction industry vigorously promotes the optimization design of green buildings; emphasizes on obeying the laws of nature and maintains ecological balance; integrates the social, cultural, and psychological needs of people into the building design; and constructs harmonious and healthy green buildings [56].

China, the United States, and Hong Kong are hot spots with a cumulative co-occurrence frequency of 160 times. Data show that China has been the largest LEED-certified market outside the United States since 2010, accounting for 9% of the global LEED-certified area, and 32% of the certified area outside the United States. By August 2017, China had a total LEED-certified area of 48 million square meters, covering 54 cities [57]. Hong Kong set up its first green building certification system of HK BEAM (Hong Kong Building Environment Assessment Method) in 1996. According to the statistics of Hong Kong Green Building Council (HKGBC), there are 1236 projects in Hong Kong that have passed the green building certification [58] Since 1 April 2011, the green building environment assessment certification has become a reward incentive. According to data released by the China Real Estate Association, there were 10,927 green building projects nationwide by the end of December 2017, with an increase of more than 3000 from the previous year, and a green buildings' area of more than 1 billion square meters [59]. Figure 5 shows the results of 3147 documents retrieved from the WoS core database, ranked by countries and regions. It can be found that scholars from China, the United States, and Hong Kong pay more attention and conduct more research on green building.

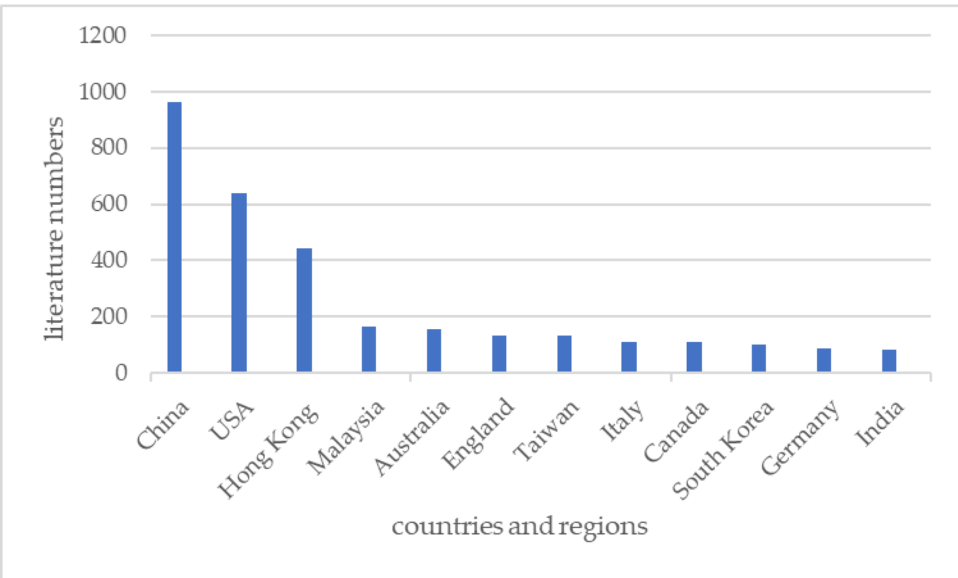


Figure 5. Major study areas of green building.

Life cycle assessment, or LCA, with a co-occurrence frequency of 156 times, quantifies the material flows and energy consumption flows of every stage of the life-cycle (from raw material acquisition to design, manufacture, utilization, recycling, and final disposal, among others), gives quantitative assessment to the life-cycle of building system and the regional environment, and figures out methods of improvement to provide the basis of analysis and decision-making for all stakeholders in the construction industry [60]. With the development of green building, accelerating the green transformation of industry including the construction industry has become an important mission for China's "green development". As a tool to comprehensively assess the green level of products, LCA has been recognized worldwide and has become an important support for the development of green building in various countries [61]. In addition, the life cycle sustainability assessment (LCSA) will be another promising and integrated approach that encompasses three aspects of environment, economy, and society, which represent the three pillars of sustainable development, namely, environmental life cycle assessment (E-LCA), cost life cycle assessment (C-LCA), and social life cycle assessment (S-LCA) [62].

The assessment standards are not the same for different types of buildings. Therefore, the type of building is also a research focus that cannot be neglected. The co-occurrence frequency of residential building/office building is 149. It is helpful to solve the existing problems in the construction industry by fully considering the types of building. At present, there are only two kinds of objects in the Assessment Standard for Green Building in China, namely, residential building and public building [63]. If all buildings are assessed according to the two green building assessment standards, it is impossible to carry out a scientific and comprehensive analysis of the building. Therefore, during the process of perfecting the green building assessment standards in China, it is necessary to further refine the types of buildings and divide them into different categories according to the actual developments of the construction industry and the national conditions of China, in order to carry out a scientific and comprehensive analysis on the buildings.

Data show that the co-occurrence frequency of energy efficiency, energy consumption, and energy saving is 137, 106, and 60, respectively. With the rapid development of the construction industry, energy consumption has become an increasingly severe problem and energy shortage has become a bottleneck for the development of economic sustainability [64]. Therefore, the high efficiency of energy utilization is increasingly a concern of governments and enterprises, showing the great significance of energy saving technologies for green building [65]. For example, Sadineni et al. conducted a detailed technical review of building envelope components and their improvements in terms of energy efficiency; discussed different types of energy-saving walls, such as Trombe wall, ventilation wall, and glass wall; and made an introduction to the achievements of energy saving rooftops such as modern green roof, photovoltaic roof, radiation transmission barrier, and cooling system of evaporative roof [66].

The environmental impact and climate change produced in the construction process are also worth noticing. The new-built constructions, reconstructions, and demolition of buildings will result in the waste of resources and energy consumption, as well as a large amount of solid waste, and finally pollute the environment [67]. The construction industry has been a leading carbon emitter for a long time. The simultaneous growth of building size, volume, and energy consumption intensity will inevitably bring tremendous carbon emission, which will be the focus of the further studies of energy conservation and emission reduction work in China [68]. Therefore, green buildings fully incorporate the green concept into the construction process, and adopt various kinds of low-carbon and environmentally friendly materials to reduce the energy consumption and improve the construction technical level of the project, which can effectively alleviate the current situation.

After meeting the basic residential needs for shelters from wind and rain, people start to pay increasing attention to the needs for living comfortably and healthily. Thermal comfort is a complex process of dynamic adjustment of temperature and humidity [69,70]. The satisfaction of building users is closely related to thermal comfort; meanwhile, the other factors of psychology, physiology, culture, or behavior of people may also react to thermal comfort. Green buildings in the future should take into full consideration the climate, indoor environmental quality, and natural ventilation to create a healthy and comfortable residential environment [71]. It is found that the health status and productivity level of people will be improved when they are working and living in green buildings [72]. The study shows the impacts of green buildings on productivity and absenteeism cannot be ignored [73].

The development of green building also comes with many challenges. Although green building seems to be more attractive from an environmental point of view, the costs are far higher than those of traditional building. In addition, some scholars have questioned the overwhelming superiority of green building in thermal comfort. For example, Paul and Taylor discovered that there is no significant difference in terms of thermal comfort between green buildings and traditional buildings equipped with heating, ventilation, and air conditioning systems [74].

The co-occurrence frequency of material selection is 55 times. Generally speaking, the existing green building materials have the problems of high production cost, complicated manufacturing process, and exclusive material selection, and they cannot be used repeatedly. In the future, the green building materials should focus on the research and development of composite materials for using the advantages of various materials to make up for the defects of single material, as well as new materials and technologies to promote development. Traditional cement and concrete are indispensable materials for building, but they waste a lot of mineral resources and will cause pollution to the environment in the production process. With the development of science and technology, eco-cement has been successfully developed, which can be degraded in the environment without solid waste [75]. Compared with the traditional cement, eco-cement can reduce the emission of carbon dioxide by 30% to 40%, and can save more than 25% of energy, with equivalent performance to that of ordinary cement. Moreover, as a green building material, recycled concrete can not only solve the disposal problem of waste concrete, but also save resources to alleviate the imbalance between supply and demand, with remarkable social, economic, and environmental benefits [76]. Cao et al. introduced the performance of concrete bar-type plank, a new type of building material, and suggested that it should be used as an external wall structure rather than a decorative part in practical application [77].

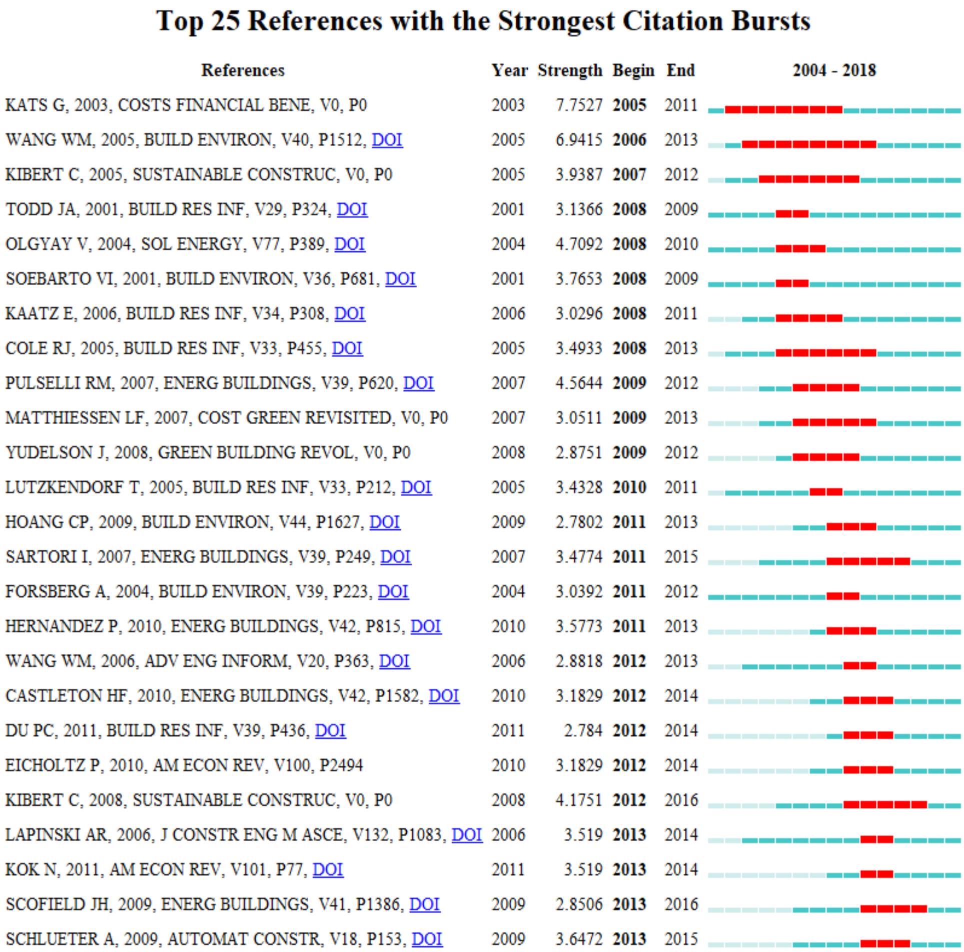
Besides, the co-occurrence frequency of emission, project, consumption, efficiency/productivity, behavior, and policy is 46, 46, 46, 45, 40, and 36, respectively. Some studies have questioned the energy efficiency of green buildings, which also arouse the attention of other scholars on the certified green building projects. Menassa et al. analyzed the energy performance of 11 LEED-certified United States Navy buildings. It showed that most of these buildings failed to reach the specified energy-saving and water-saving targets [78]. As a matter of fact, most of these buildings consumed more energy than that of the national average. Darko et al. made a systematic review of green building, finding that the most mentioned words in the references are inadequate information, imperfect incentives, and absence of interests [79].

Utilizing renewable energy sources such as solar energy, wind energy, hydropower, and geothermal energy are the key to achieve the development of green building [80]. At the same time, it is necessary to integrate the concepts of modern information technology, services, and management to provide a more convenient, safe, and energy-saving living environment for people [81]; adhere to local conditions; improve the standard system and legal system of green building; strengthen incentives; supervise the whole process of construction; attach great importance to the education of green building; strive to improve the awareness of participants; and introduce some educational-related indicators into the existing green building assessment tools [82].

In addition to the abovementioned keywords, consideration should also be given to the problems involved in the following keywords, including structural frames of buildings, mechanical properties of building materials, embodied energies, and thermal performances of buildings, among others. At the same time, it is needed to reduce waste, lay emphasis on recycling, and improve the efficiency of resource utilization, so as to meet the requirements of the green building certification and realize sustainable development. In a word, it is complicated to promote the healthy development of green building and maintain the balance of all parties, which still has a long way to go.

3.2. Knowledge Evolution of Green Building in the Extended Database

A citation burst indicates that the scientific community has paid or is paying particular attention to these articles [22]. In this paper, CiteSpace is used to conduct a visualized analysis of 3758 articles in the extended database, which can identify the references with strong citation bursts. Figure 6 shows the top 25 references with the strongest citation bursts. According to the existing functions of CiteSpace, there are two ways to sort references with citation burst: by the starting time of the burst and by the strength of the burst; the way of sorting by starting time is selected in this article.



Top 25 References with the Strongest Citation Bursts

References	Year	Strength	Begin	End	2004 - 2018
KATS G, 2003, COSTS FINANCIAL BENE, V0, P0	2003	7.7527	**2005**	2011	
WANG WM, 2005, BUILD ENVIRON, V40, P1512, DOI	2005	6.9415	**2006**	2013	
KIBERT C, 2005, SUSTAINABLE CONSTRUC, V0, P0	2005	3.9387	**2007**	2012	
TODD JA, 2001, BUILD RES INF, V29, P324, DOI	2001	3.1366	**2008**	2009	
OLGYAY V, 2004, SOL ENERGY, V77, P389, DOI	2004	4.7092	**2008**	2010	
SOEBARTO VI, 2001, BUILD ENVIRON, V36, P681, DOI	2001	3.7653	**2008**	2009	
KAATZ E, 2006, BUILD RES INF, V34, P308, DOI	2006	3.0296	**2008**	2011	
COLE RJ, 2005, BUILD RES INF, V33, P455, DOI	2005	3.4933	**2008**	2013	
PULSELLI RM, 2007, ENERG BUILDINGS, V39, P620, DOI	2007	4.5644	**2009**	2012	
MATTHIESSEN LF, 2007, COST GREEN REVISITED, V0, P0	2007	3.0511	**2009**	2013	
YUDELSON J, 2008, GREEN BUILDING REVOL, V0, P0	2008	2.8751	**2009**	2012	
LUTZKENDORF T, 2005, BUILD RES INF, V33, P212, DOI	2005	3.4328	**2010**	2011	
HOANG CP, 2009, BUILD ENVIRON, V44, P1627, DOI	2009	2.7802	**2011**	2013	
SARTORI I, 2007, ENERG BUILDINGS, V39, P249, DOI	2007	3.4774	**2011**	2015	
FORSBERG A, 2004, BUILD ENVIRON, V39, P223, DOI	2004	3.0392	**2011**	2012	
HERNANDEZ P, 2010, ENERG BUILDINGS, V42, P815, DOI	2010	3.5773	**2011**	2013	
WANG WM, 2006, ADV ENG INFORM, V20, P363, DOI	2006	2.8818	**2012**	2013	
CASTLETON HF, 2010, ENERG BUILDINGS, V42, P1582, DOI	2010	3.1829	**2012**	2014	
DU PC, 2011, BUILD RES INF, V39, P436, DOI	2011	2.784	**2012**	2014	
EICHOLTZ P, 2010, AM ECON REV, V100, P2494	2010	3.1829	**2012**	2014	
KIBERT C, 2008, SUSTAINABLE CONSTRUC, V0, P0	2008	4.1751	**2012**	2016	
LAPINSKI AR, 2006, J CONSTR ENG M ASCE, V132, P1083, DOI	2006	3.519	**2013**	2014	
KOK N, 2011, AM ECON REV, V101, P77, DOI	2011	3.519	**2013**	2014	
SCOFIELD JH, 2009, ENERG BUILDINGS, V41, P1386, DOI	2009	2.8506	**2013**	2016	
SCHLUETER A, 2009, AUTOMAT CONSTR, V18, P153, DOI	2009	3.6472	**2013**	2015	

Figure 6. Top 25 references with the strongest citation bursts.

As you can see from Figure 6, all of the citation bursts started since 2005. The strongest citation burst is related to a report by Kats, focusing on the cost-effectiveness of green buildings [83]. The report points out that the earlier you incorporate the features of green building into the design process, the lower the cost will be. Despite the limited data and the need to validate in all types of buildings, green building still has an overall cost advantage. Especially for early green building projects, the overall economic benefits are ten times more than the initial investment required by design and construction procedures [68].

The second strongest citation burst, started from 2006, is related to the studies of Wang et al., focusing on optimization for green building design. The authors proposed a multi-objective optimization model and adopted the life cycle assessment method to evaluate the economic and environmental conditions of the design scheme. Through empirical research, it was proven that the method is very useful in the optimization for green building design [84]. In addition, issued in 2006, an article from Wang et al. about the floor shape optimization for green building design has attracted the attention of scholars since 2012. According to the article, the optimal design of floor shape has an important impact on energy performance and construction cost; therefore, a genetic algorithm is proposed to optimize the shape of building [85].

The book *Sustainable Construction: Green Building Design and Delivery* by Kibert caused two citation bursts. In the first edition (2005), the author used the LEED standard to assess green buildings to achieve the ecological and economic benefits [86]. In the revision of 2008, Kibert added Green Globes and other building assessment systems in various countries and focused on the design and construction procedures of high-performance green buildings [87].

The citation bursts that began in 2008 are related to green building assessment tools. Todd et al. introduced the Green Building Challenge (GBC), one of the earliest assessment frameworks; compared the similarities and differences between GBC and other assessment tools; and concluded that the role of GBC is to promote the development of the building performance assessment system by exploiting, testing, and discussing assessment criteria and tools according to their characteristics and advantages [88]. Olgyay and Herdt integrated the concept of ecological carrying capacity into the construction environment, and regarded the carrying capacity as a time- and region-related tool to assess the impact of the building on the environment [89]. Soebarto and Williamson proposed a method to promote the performance design of the building based on the multi-objective decision-making method [90]. Kaatz et al. pondered the potential measures to promote sustainable construction; redefined the methods and objectives of building assessment; and put forward three important results of sustainable building assessment, namely, integration, transparency, and collaborative learning [91]. Cole made a comparative analysis of different assessment methods, which provides a reference for the further development of assessment methods [92].

The citation bursts that began in 2009 are related to Pulselli et al. [93], Matthiessen et al. [94], and Yudelson [95], focusing on the environmental issues of the building. To be specific, Pulselli et al. used energy consumption analyses in the process of construction, maintenance, and utilization of the building, and adopted comprehensive environmental accounting approaches and global sustainability indicators to assess the environmental performance of the building [93]. Matthiessen et al. reviewed the feasibility of sustainable design and its costs under the circumstances of increasing attention to sustainability, and integrated sustainable design into the project costs [94]. Yudelson, author of the book *The Green Building Revolution*, argued that the environmental issues have attracted worldwide attention, and a "revolution" is penetrating into every aspect of the construction industry [95].

The citation bursts that began in 2011 are related to Hoang et al. [96], Sartori et al. [97], Hernandez et al. [98], and Forsberg et al. [99]. With the development of the green building market, various kinds of green building materials have emerged. Some of the green materials may have a significant oxidation reaction and reduce the indoor ozone. Hoang et al. quantified the ozone removal rate according to the deposition rate and the reaction probability. It was found that the ozone removal rate is inversely proportional to the removal time after the initial exposure [96]. The energy consumption of 60 buildings in 9 countries was analyzed by Sartori et al., indicating that the low energy consumption building will bring net benefits in the life cycle [97]. In addition, the zero energy consumption building has also attracted people's attention. Hernandez et al. applied the concept of net energy into the building environment analysis, proposed the definition of life cycle zero energy consumption building (LC-ZEB), and took the net energy ratio (NER) as a factor to help the design for buildings from the perspective of life-cycle [98]. In the past few decades, the construction industry has imposed a load on the environment. Therefore, we need some qualitative and quantitative tools for environmental assessment. Forsberg et al. described and compared five different tools for building environmental assessment, the purpose of which is to help us understand their advantages and disadvantages through the analysis of different tools, so as to provide references for decision makers [99].

The citation bursts that began in 2012 and 2013 are related to energy efficiency, energy conservation and emission reduction, and environmental sustainability, and focus on the way to promote the development of green building with modern information technology. For example, Castleton et al. described the potential benefits of green rooftops in terms of building energy consumption, highlighting the circumstances in which energy conservation can be maximized [100]. Du Plessis and Cole questioned the concept of "stakeholders" and the traditional model of sustainable development, and proposed a new sustainable development model that can promote the transformation of the construction industry [101]. Eichholtz et al. systematically analyzed the impact of environmentally sustainable buildings on the market economy for the first time, proving that the economic value of green building comes from objective market transactions rather than engineering cost estimates. The research also showed that there is an important relationship between the change of a green office building premium and its energy-saving characteristics [102]. At present, most of the delivery methods have energy waste. However, lean production principles have been shown to reduce waste and improve performance in a highly complicated production environment. Lapinski et al. drew the capital facility delivery process of Toyota, showing the way to deliver sustainable projects successfully and economically [103]. Kok et al. analyzed the distribution of energy efficiency certified buildings in the real estate market of the United States. The results showed that about 30% of the commercial office space in the 48 largest cities had been certified as "Energy Star" and about 11% of the office space was LEED-certified as sustainable by 2010 [104]. Scofield demonstrated that most of the LEED-certified offices use less energy than comparable non-LEED-certified offices, but he did not distinguish between the energy source of LEED-certified buildings and traditional buildings [36]. Schlueter and Thesseling emphasized the establishment of energy performance assessment based on BIM at the early design stage [53].

4. Knowledge Graph for Green Building

The knowledge base, knowledge domain, and knowledge evolution of green building are clearly visualized and analyzed using the method of bibliometrics, and are integrated to build a green building knowledge graph, as shown in Figure 7.

As can be seen from Figure 7, the knowledge graph for green building is composed of the knowledge base, knowledge domain, and knowledge evolution. The green building knowledge base includes keywords identified by the co-occurrence network. The green building knowledge domain is identified by cluster analysis, which can help us better understand the main research fields of green building, including technology adoption, material selection, panel data method, green building project management, and green building assessment system (building assessment tools). These clusters are further divided into the technical system, the management system, and the assessment system. Among them, the technical system refers to the relevant technical means adopted in the life-cycle of building in order to meet the requirements of green building; the assessment system refers to a set of objective, fair, and local index system and assessment methods that can be quantitatively evaluated in order to promote real green building [105]; and green building project management includes scope management, time management, cost management, quality management, schedule management, human resources management, communication management, risk management, procurement management, integrated management and so on [106]. These three systems are effective pillars for the smooth implementation of green building. The knowledge evolution of green building is briefly shown as follows. In the early stages of green building development, most of the attention is focused on cost and benefits (2005–2011) and environmental quality (2006–2013); with the development of the construction industry, material selection (2011–2013), energy efficiency (2011–2015), lean production (2013–2014), energy saving (2013–2016), optimal design (2012–2016), and information technology (2013–2016) have become the research focuses. It is worth noting that the assessment system for green buildings received extensive attention in both time periods of 2012–2016 and 2008–2015.

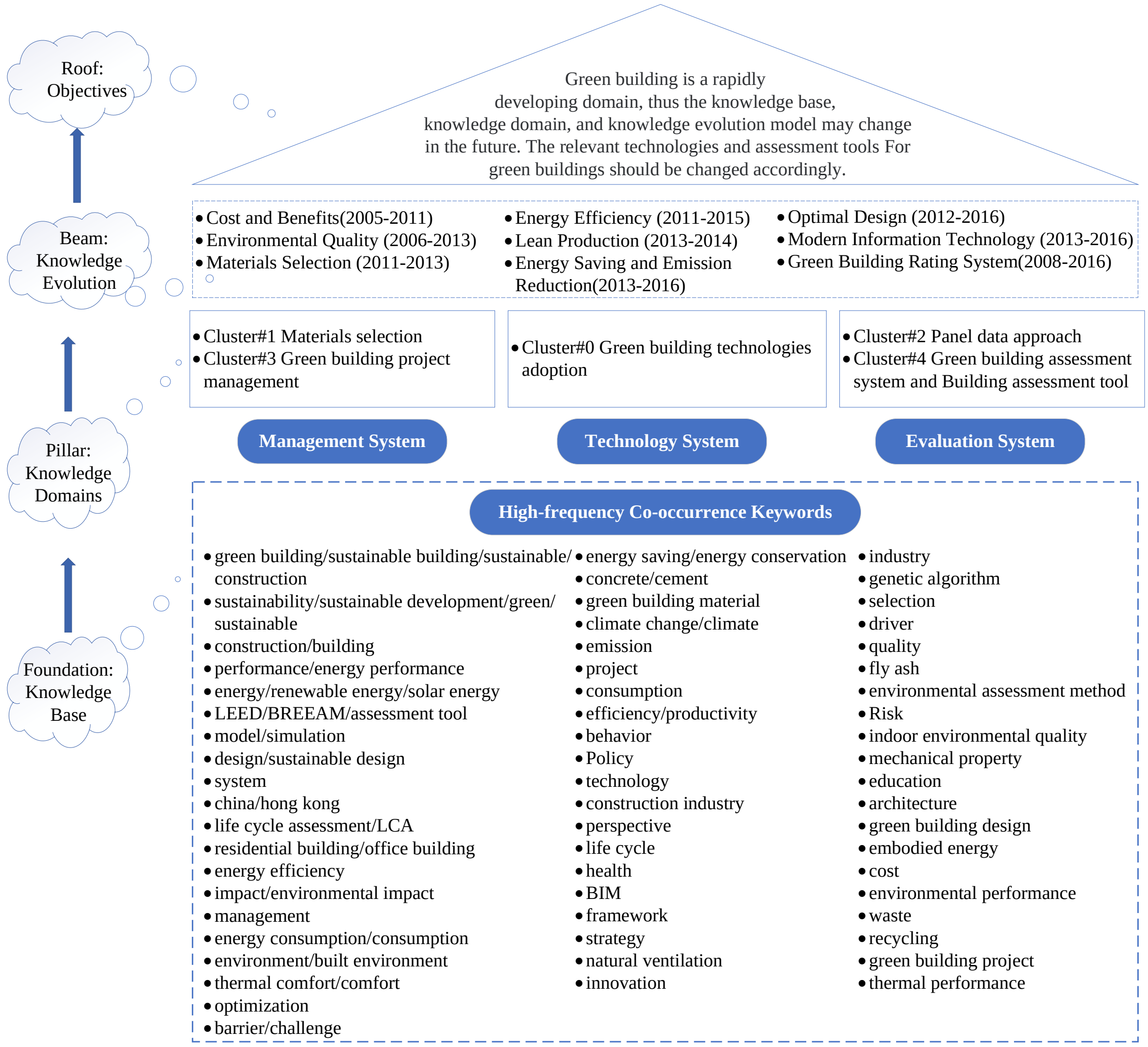


Figure 7. Knowledge graph of green building.

Through analyzing the knowledge base, knowledge domain, and knowledge evolution of green building, the knowledge frame and development process of the green building discipline can be understood. Green building is a rapidly developing domain, thus the knowledge base, knowledge domain, and knowledge evolution model may change in the future. The relevant technologies and assessment tools for green buildings should be changed accordingly. For example, the establishment of BIM for green building via advanced modern information technology will play an important role in the development of green building. By reading a large number of documents, it is found that BIM technology has not been fully applied in the project operational stage, and the integrated optimization of BIM is still imperfectly applicable to the green building certification system. Therefore, realizing the collaborative management of BIM in each stage is the key of future research. In addition, it will be the main development trend in the future to incorporate modern information technology, services, and management as a whole, and to provide a more convenient, safer, and energy-saving living environment for people in terms of building construction [107].

5. Conclusions

On the basis of 3147 articles in the core database and 3758 articles in the extended database related to green building, this paper analyzed the existing knowledge system of green building using CiteSpace, and obtained the following results.

(1) As shown in Table 3, this paper identified the keywords of the green building knowledge base using the function of keyword co-occurrence analysis, among which green building, sustainable development, construction, performance, energy, assessment tools, and other 60 keywords are relatively important.

(2) As shown in Figure 3, five major clusters including the green building technologies adoption, materials selection, panel data approach, green building project management, and green building assessment system were recognized and can be further divided into the technical system, the management system, and the assessment system using cluster analysis, which can be regarded as the knowledge domain of green building.

(3) As shown in Figure 6, the knowledge evolution of green building was analyzed by using citation bursts, revealing how research related to green building has evolved over time.

The unique value of this paper is to build a knowledge graph for green building based on keywords, clusters, and citation bursts using the function of quantitative analysis of CiteSpace. In the future, the data can be updated regularly to carry out relevant research, so that we can further improve the green building knowledge graph provided by this study.

Author Contributions: Y.S. contributed to the conception and design. X.L. performed research and analyzed the data. All of the authors drafted and revised the manuscript together and approved its final publication.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bhutta, F.M. Application of smart energy technologies in building sector-future prospects. In Proceedings of the 2017 International Conference on Energy Conservation and Efficiency (ICECE), Lahore, Pakistan, 22–23 November 2017; pp. 7–10.
2. Abdallah, M.; El-Rayes, K.; Liu, L. Optimizing the selection of sustainability measures to minimize life-cycle cost of existing buildings. *Can. J. Civ. Eng.* **2016**, *43*, 151–163. [CrossRef]
3. Lu, Y.; Peng, C.; Li, D. Which activities contribute most to building energy consumption in China? A hybrid LMDI decomposition analysis from year 2007 to 2015. *Energy Build.* **2018**, *165*, 259–269. [CrossRef]
4. Chatterjee, D.K. World Commission on Environment and Development. *Environ. Policy Law* **1987**, *14*, 26–30.
5. McCammon, A.L. United Nations Conference on Environment and Development, held in Rio de Janeiro, Brazil, during 3–14 June 1992, and the '92 Global Forum, Rio de Janeiro, Brazil, 1–14 June 1992. *Environ. Conserv.* **1992**, *19*, 372–373. [CrossRef]
6. Strong, M.F. *The Global Partnership for Environment and Development. A guide to Agenda 21*; The United Nations Conference on Environment and Development: Rio de Janeiro, Brazil, 1992.
7. Alawneh, R.; Ghazali, F.; Ali, H.; Asif, M. A new index for assessing the contribution of energy efficiency in LEED 2009 certified green buildings to achieving UN sustainable development goals in Jordan. *Int. J. Green Energy* **2019**, *16*, 490–499. [CrossRef]
8. Darko, A.; Chan, A.P.C.; Yang, Y.; Shan, M.; He, B.J.; Gou, Z.H. Influences of barriers, drivers, and promotion strategies on green building technologies adoption in developing countries: The Ghanaian case. *J. Clean. Prod.* **2018**, *200*, 687–703. [CrossRef]
9. Ghaffarian-Hoseini, A.; Dahlan, N.D.; Berardi, U.; GhaffarianHoseini, A.; Makaremi, N.; GhaffarianHoseini, M. Sustainable energy performances of green buildings: A review of current theories, implementations and challenges. *Renew. Sustain. Energy Rev.* **2013**, *25*, 1–17. [CrossRef]
10. Wong, J.K.W.; Zhou, J. Enhancing environmental sustainability over building life cycles through green BIM: A review. *Autom. Constr.* **2015**, *57*, 156–165. [CrossRef]
11. Darko, A.; Chan, A.P.C. Critical analysis of green building research trend in construction journals. *Habitat Int.* **2016**, *57*, 53–63. [CrossRef]
12. Ulubeyli, S.; Kazanci, O. Holistic sustainability assessment of green building industry in Turkey. *J. Clean. Prod.* **2018**, *202*, 197–212. [CrossRef]

13. Darko, A.; Chan, A.P.C.; Huo, X.S.; Owusu-Manu, D. A scientometric analysis and visualization of global green building research. *Build. Environ.* **2019**, *149*, 501–511. [CrossRef]
14. Chen, C.M. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *J. Am. Soc. Inf. Sci. Tec.* **2006**, *57*, 359–377. [CrossRef]
15. Zuo, J.; Zhao, Z.Y. Green building research–current status and future agenda: A review. *Renew. Sustain. Energy Rev.* **2014**, *30*, 271–281. [CrossRef]
16. Li, X.; Wu, P.; Shen, G.Q.P.; Wang, X.Y.; Teng, Y. Mapping the knowledge domains of building information modeling (BIM): A bibliometric approach. *Autom. Constr.* **2017**, *84*, 195–206. [CrossRef]
17. Jiang, Y.F.; Hou, L.Y.; Shi, T.M.; Gui, Q.C. A review of urban planning research for climate change. *Sustainability* **2017**, *9*, 2224. [CrossRef]
18. Zhao, X.; Wang, S.; Wang, X. Characteristics and trends of research on new energy vehicle reliability based on the web of science. *Sustainability* **2018**, *10*, 3560. [CrossRef]
19. Chen, C.M.; Hu, Z.G.; Liu, S.B.; Tseng, H. Emerging trends in regenerative medicine: A scientometric analysis in CiteSpace. *Expert Opin. Biol. Ther.* **2012**, *12*, 593–608. [CrossRef]
20. Schneider, J.W. Mapping scientific frontiers: The quest for knowledge visualization. *J. Am. Soc. Inf. Sci. Technol.* **2004**, *55*, 363–365. [CrossRef]
21. Zhu, J.; Hua, W.J. Visualizing the knowledge domain of sustainable development research between 1987 and 2015: A bibliometric analysis. *Scientometrics* **2017**, *110*, 893–914. [CrossRef]
22. Su, H.N.; Lee, P.C. Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in technology foresight. *Scientometrics* **2010**, *85*, 65–79. [CrossRef]
23. Hosseini, M.R.; Martek, I.; Zavadskas, E.K.; Aibinu, A.A.; Arashpour, M.; Chileshe, N. Critical evaluation of off-site construction research: A scientometric analysis. *Autom. Constr.* **2018**, *87*, 235–247. [CrossRef]
24. Hou, J.H.; Yang, X.C.; Chen, C.M. Emerging trends and new developments in information science: A document co-citation analysis (2009–2016). *Scientometrics* **2018**, *115*, 869–892. [CrossRef]
25. Chen, C.M.; Dubin, R.; Kim, M.C. Orphan drugs and rare diseases: A scientometric review (2000–2014). *Expert Opin. Orphan Drugs* **2014**, *2*, 709–724. [CrossRef]
26. Wong, S.C.; Abe, N. Stakeholders' perspectives of a building environmental assessment method: The case of CASBEE. *Build. Environ.* **2014**, *82*, 502–516. [CrossRef]
27. Chen, C.; Chen, Y. Searching for clinical evidence in CiteSpace. *AMIA Annu. Symp. Proc.* **2005**, 121–125.
28. Newsham, G.R.; Mancini, S.; Birt, B.J. Do LEED-certified buildings save energy? Yes, but . . . . *Energy Build.* **2009**, *41*, 897–905. [CrossRef]
29. Ali, H.H.; Al Nsairat, S.F. Developing a green building assessment tool for developing countries–Case of Jordan. *Build. Environ.* **2009**, *44*, 1053–1064. [CrossRef]
30. Ding, G.K. Sustainable construction-the role of environmental assessment tools. *J. Env. Manag.* **2008**, *86*, 451–464. [CrossRef]
31. Haapio, A.; Viitaniemi, P. A critical review of building environmental assessment tools. *Environ. Impact Assess. Rev.* **2008**, *28*, 469–482. [CrossRef]
32. Robichaud, L.B.; Anantatmula, V.S. Greening project management practices for sustainable construction. *J. Manag. Eng.* **2011**, *27*, 48–57. [CrossRef]
33. Ortiz, O.; Castells, F.; Sonnemann, G. Sustainability in the construction industry: A review of recent developments based on LCA. *Constr. Build. Mater.* **2009**, *23*, 28–39. [CrossRef]
34. Hwang, B.G.; Tan, J.S. Green building project management: Obstacles and solutions for sustainable development. *Sustain. Dev.* **2012**, *20*, 335–349. [CrossRef]
35. Zhang, X.; Platten, A.; Shen, L. Green property development practice in China: Costs and barriers. *Build. Environ.* **2011**, *46*, 2153–2160. [CrossRef]
36. Scofield, J.H. Do LEED-certified buildings save energy? Not really . . . . *Energy Build.* **2009**, *41*, 1386–1390. [CrossRef]
37. Dunning, T. Accurate methods for the statistics of surprise and coincidence. *Comput. Linguist.* **1993**, *19*, 61–74.
38. Darko, A.; Chan, A.P.C. Strategies to promote green building technologies adoption in developing countries: The case of Ghana. *Build. Environ.* **2018**, *130*, 74–84. [CrossRef]
39. Liu, J. Evaluation of green building energy-saving technology based on entropy weight method. *Appl. Mech. Mater.* **2017**, *865*, 301–305.

40. Akadiri, P.O.; Olomolaiye, P.O. Development of sustainable assessment criteria for building materials selection. *Eng. Constr. Archit. Manag.* **2012**, *19*, 666–687. [CrossRef]
41. Akadiri, P.O.; Olomolaiye, P.O.; Chinyio, E.A. Multi-criteria evaluation model for the selection of sustainable materials for building projects. *Autom. Constr.* **2013**, *30*, 113–125. [CrossRef]
42. Islam, N. Growth empirics: A panel data approach. *Q. J. Econ.* **1998**, *113*, 319–323. [CrossRef]
43. Coban, S.; Topcu, M. The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. *Energy Econ.* **2013**, *39*, 81–88. [CrossRef]
44. Chang, T.Y.; Chu, H.P.; Chen, W.Y. Energy consumption and economic growth in 12 Asian countries: Panel data analysis. *Appl. Econ. Lett.* **2013**, *20*, 282–287. [CrossRef]
45. Wu, P.; Low, S.P. Project management and green buildings: Lessons from the rating systems. *J. Prof. Issues Eng. Educ. Pract.* **2010**, *136*, 64–70. [CrossRef]
46. Kainer, K.A.; DiGiano, M.L.; Duchelle, A.E.; Wadt, L.H.O.; Bruna, E.; Dain, J.L. Partnering for greater success: Local stakeholders and research in tropical biology and conservation. *Biotropica* **2009**, *41*, 555–562. [CrossRef]
47. Shenhar, A.; Dvir, D. Project management research-the challenge and opportunity. *IEEE Eng. Manag. Rev.* **2008**, *36*, 112–121. [CrossRef]
48. Rastogi, A.; Choi, J.K.; Hong, T.; Lee, M. Impact of different LEED versions for green building certification and energy efficiency rating system: A multifamily midrise case study. *Appl. Energy* **2017**, *205*, 732–740. [CrossRef]
49. Haroglu, H. The impact of Breeam on the design of buildings. In Proceedings of the Institution of Civil Engineers-Engineering Sustainability, Reading, UK, 1 February 2013; Volume 166, pp. 11–19.
50. Sinou, M.; Bidou, D. The HQE approach. *Manag. Environ. Qual. Int. J.* **2006**, *17*, 587–592.
51. Chang, K.F.; Chiang, C.M.; Chou, P.C. Adapting aspects of GBTool 2005—searching for suitability in Taiwan. *Build. Environ.* **2007**, *42*, 310–316. [CrossRef]
52. Liu, P.; Lei, J.H. The comparative analysis of Chinese green building assessment system and foreign evaluation system. *Adv. Mater. Res.* **2014**, *1004*, 1547–1550. [CrossRef]
53. Schlueter, A.; Thesseling, F. Building information model based energy/exergy performance assessment in early design stages. *Autom. Constr.* **2009**, *18*, 153–163. [CrossRef]
54. Scherer, R.J.; Schapke, S.E. A distributed multi-model-based management information system for simulation and decision-making on construction projects. *Adv. Eng. Inform.* **2011**, *25*, 582–599. [CrossRef]
55. Shi, L.; Chew, M.Y.L. A review on sustainable design of renewable energy systems. *Renew. Sustain. Energy Rev.* **2012**, *16*, 192–207. [CrossRef]
56. Polatidis, H.; Haralambopoulos, D.A. Decomposition analysis and design of sustainable renewable energy systems: A new approach. *Energy Sources Part. B Econ. Plan. Policy* **2007**, *2*, 371–380. [CrossRef]
57. Scofield, J.H.; Doane, J. Energy performance of LEED-certified buildings from 2015 Chicago benchmarking data. *Energy Build.* **2018**, *174*, 402–413. [CrossRef]
58. Chen, X.; Yang, H.; Zhang, W. A comprehensive sensitivity study of major passive design parameters for the public rental housing development in Hong Kong. *Energy* **2015**, *93*, 1804–1818. [CrossRef]
59. Gou, Z.; Xie, X. Evolving green building: Triple bottom line or regenerative design? *J. Clean. Prod.* **2012**, *30*, 14–22. [CrossRef]
60. Chau, C.K.; Leung, T.M.; Ng, W.Y. A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings. *Appl. Energy* **2015**, *143*, 395–413. [CrossRef]
61. Yu, X.; Su, Y. Daylight availability assessment and its potential energy saving estimation—A literature review. *Renew. Sustain. Energy Rev.* **2015**, *52*, 494–503. [CrossRef]
62. Wang, J.; Li, X.L.; Li, S.S. Energy saving program that replaces water chiller with combined air-energy saving system and water-energy saving system. *Achiev. Eng. Mater. Energy Manag. Control. Based Inf. Technol.* **2011**, *171*, 201–204. [CrossRef]
63. Shan, M.; Hwang, B.G. Green building rating systems: Global reviews of practices and research efforts. *Sustain. Cities Soc.* **2018**, *39*, 172–180. [CrossRef]
64. Xu, P.; Chan, E.H.; Qian, Q.K. Success factors of energy performance contracting (EPC) for sustainable building energy efficiency retrofit (BEER) of hotel buildings in China. *Energy Policy* **2011**, *39*, 7389–7398. [CrossRef]

65. Kua, H.W.; Wong, C.L. Analysing the life cycle greenhouse gas emission and energy consumption of a multi-storied commercial building in Singapore from an extended system boundary perspective. *Energy Build.* **2012**, *51*, 6–14. [CrossRef]
66. Sadineni, S.B.; Madala, S.; Boehm, R.F. Passive building energy savings: A review of building envelope components. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3617–3631. [CrossRef]
67. Hong, B.; Lin, B.R. Numerical studies of the outdoor wind environment and thermal comfort at pedestrian level in housing blocks with different building layout patterns and trees arrangement. *Renew. Energ* **2015**, *73*, 18–27. [CrossRef]
68. Bodart, M.; Herde, A.D. Global energy savings in offices buildings by the use of daylighting. *Energy Build.* **2002**, *34*, 421–429. [CrossRef]
69. Al-Homoud, M.S. Thermal design of office buildings. *Int. J. Energy Res.* **2015**, *21*, 941–957. [CrossRef]
70. Yu, W.; Li, B.; Jia, H.; Zhang, M. Application of multi-objective genetic algorithm to optimize energy efficiency and thermal comfort in building design. *Energy Build.* **2015**, *88*, 135–143. [CrossRef]
71. Frontczak, M.; Schiavon, S.; Goins, J. Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. *Indoor Air* **2012**, *22*, 119–131. [CrossRef]
72. Jenkins, H. Natural ventilation in buildings: Measurement in a wind tunnel and numerical simulation with large eddy simulation. *J. Wind Eng. Ind. Aerodyn.* **2003**, *91*, 331–353.
73. Thachter, A.; Milner, K. Changes in productivity, psychological wellbeing and physical wellbeing from working in a 'green' building. *Work* **2014**, *49*, 381–393.
74. Paul, W.L.; Taylor, P.A. A comparison of occupant comfort and satisfaction between a green building and a conventional building. *Build. Environ.* **2008**, *43*, 1858–1870. [CrossRef]
75. Hunag, L.J.; Wang, H.Y.; Wang, S.Y. A study of the durability of recycled green building materials in lightweight aggregate concrete. *Constr. Build. Mater.* **2015**, *96*, 353–359. [CrossRef]
76. De Schepper, M.; van den Heede, P.; van Driessche, I.; de Belie, N. Life cycle assessment of completely recyclable concrete. *Materials* **2014**, *7*, 6010–6027. [CrossRef] [PubMed]
77. Cao, Y.; Yang, J.P. Application of concrete bar-type plank in constructional engineering-a case study of state key laboratory for green building materials. *Adv. Mater. Res.* **2011**, *168*, 1648–1652. [CrossRef]
78. Menassa, C.; Mangasarian, S.; El Asmar, M.; Kirar, C. Energy consumption evaluation of U.S. navy LEED-certified buildings. *J. Perform. Constr. Facil.* **2012**, *26*, 46–53. [CrossRef]
79. Darko, A.; Zhang, C.Z.; Chan, A.P.C. Drivers for green building: A review of empirical studies. *Habitat Int.* **2017**, *60*, 34–49. [CrossRef]
80. Chang, J.Y.; Kuan, Y.D.; Liou, S.S. Integration of renewable energy technology in building. *Appl. Mech. Mater.* **2011**, *71*, 2336–2342. [CrossRef]
81. Trowbridge, M.J.; Worden, K.; Pyke, C. Using green building as a model for making health promotion standard in the built environment. *Health Aff.* **2016**, *35*, 2062–2067. [CrossRef]
82. Liu, Q.B.; Zhang, N.; Liu, P.F. The research in programme of action and regulations promoting the development of green building. *Adv. Mater. Res-Switz.* **2012**, *361*, 1051–1055. [CrossRef]
83. The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force. Available online: https://noharm-uscanada.org/sites/default/files/documents-files/34/Building_Green_Costs_Benefits.pdf (accessed on 6 July 2019).
84. Wang, W.; Zmeureanu, R.; Rivard, H. Applying multi-objective genetic algorithms in green building design optimization. *Build. Environ.* **2005**, *40*, 1512–1525. [CrossRef]
85. Wang, W.; Rivard, H.; Zmeureanu, R. Floor shape optimization for green building design. *Adv. Eng. Inform.* **2006**, *20*, 363–378. [CrossRef]
86. Kibert, C.J. *Sustainable Construction: Green Building Design and Delivery*, 1st ed.; John Wiley: Hoboken, NJ, USA, 2005; p. 434.
87. Kibert, C.J. *Sustainable Construction: Green Building Design and Delivery*, 2nd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2008; p. 407.
88. Todd, J.A.; Crawley, D.; Geissler, S.; Lindsey, G. Comparative assessment of environmental performance tools and the role of the green building challenge. *Build. Res. Inf.* **2010**, *29*, 324–335. [CrossRef]
89. Olgyay, V.; Herdt, J. The application of ecosystems services criteria for green building assessment. *Sol. Energy* **2004**, *77*, 389–398. [CrossRef]

90. Soebarto, V.I.; Williamson, T.J. Multi-criteria assessment of building performance: Theory and implementation. *Build. Environ.* **2001**, *36*, 681–690. [CrossRef]
91. Kaatz, E.; Root, D.S.; Bowen, P.A.; Hill, R.C. Advancing key outcomes of sustainability building assessment. *Build. Res. Inf.* **2006**, *34*, 308–320. [CrossRef]
92. Cole, R.J. Building environmental assessment methods: Redefining intentions and roles. *Build. Res. Inf.* **2005**, *33*, 455–467. [CrossRef]
93. Pulselli, R.M.; Simoncini, E.; Pulselli, F.M.; Bastianoni, S. Emergy analysis of building manufacturing, maintenance and use: Em-building indices to evaluate housing sustainability. *Energy Build.* **2007**, *39*, 620–628. [CrossRef]
94. Matthiessen, L.F. *The Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in the Light of Increased Market Adoption*; In Council on Tall Buildings and Urban Habitat, Davis Langdon: Melbourne, Australia, 2007.
95. Yudelson, J. *The Green Building Revolution*, 1st ed.; Island Press: Washington, WA, USA, 2008; p. 242.
96. Hoang, C.P.; Kinney, K.A.; Corsi, R.L. Ozone removal by green building materials. *Build. Environ.* **2009**, *44*, 1627–1633. [CrossRef]
97. Sartori, I.; Hestnes, A.G. Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy Build.* **2007**, *39*, 249–257. [CrossRef]
98. Hernandez, P.; Kenny, P. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). *Energy Build.* **2010**, *42*, 815–821. [CrossRef]
99. Forsberg, A.; von Malmborg, F. Tools for environmental assessment of the built environment. *Build. Environ.* **2004**, *39*, 223–228. [CrossRef]
100. Castleton, H.F.; Stovin, V.; Beck, S.B.M.; Davison, J.B. Green roofs; building energy savings and the potential for retrofit. *Energy Build.* **2010**, *42*, 1582–1591. [CrossRef]
101. Du Plessis, C.; Cole, R.J. Motivating change: Shifting the paradigm. *Build. Res. Inf.* **2011**, *39*, 436–449. [CrossRef]
102. Eichholtz, P.; Kok, N.; Quigley, J.M. Doing well by doing good? Green office buildings. *Am. Econ. Rev.* **2010**, *100*, 2492–2509. [CrossRef]
103. Lapinski, A.R.; Horman, M.J.; Riley, D.R. Lean processes for sustainable project delivery. *J. Constr. Eng. Manag. ASCE* **2006**, *132*, 1083–1091. [CrossRef]
104. Kok, N.; McGraw, M.; Quigley, J.M. The diffusion of energy efficiency in building. *Am. Econ. Rev.* **2011**, *101*, 77–82. [CrossRef]
105. Mao, D.; Zhou, K.; Zheng, S.J.; Liu, Y.D.; Liu, Y.P. Research on evaluation system of green building in China. *Green Build. Technol. Mater.* **2011**, *224*, 159–163. [CrossRef]
106. Yin, Y.L.; Qian, K. Construction project cost management based on BIM technology. *Appl. Mech. Mater.* **2013**, *357*, 2147–2152. [CrossRef]
107. Feng, X.J. Design of a green intelligent building. *Mod. Technol. Mater. Mech. Intell. Syst.* **2014**, *1049*, 357–361. [CrossRef]