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A Scientometric Analysis of Low Carbon Building Research

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Abstract

Due to global climate change, carbon reduction has become the critical issue for the construction industry. Low carbon building (LCB) has been adopted as a strategic objective, and its implementation demonstrates the enormous potential from reducing carbon emissions and energy consumption. However, few studies have been done to examine the knowledge structure of low carbon building research, which is necessary to guide scholars and practitioners. Therefore, this paper aims to provide a comprehensive analysis of research areas regarding low carbon building using the scientometrics method. A total of 378 low carbon building related publications were collected and reviewed. Based on a co-word analysis, co-citation analysis and cluster analysis, a knowledge structure of LCBs research was developed. The knowledge structure is useful for directing future research on low carbon building. The results are also helpful for various stakeholders to have a better understanding of low carbon building research and future directions.

Keywords: low carbon building; scientometric; literature review; knowledge structure

1. Introduction

Over the past two decades, sustainable development has been challenged by the issues of climate change (Seneviratne et al., 2016). Previous studies showed that one of the major contributors to climate change is the building and construction sector (Shi et al., 2015b). Buildings and construction together account for 36% of global final energy use and 39% of energy-related CO_2 emissions in 2015 (Dean et al., 2016). The amount of CO_2 emissions that construction can influence is more significant in UK, accounting for almost 47% of total CO_2 emissions of the UK (BIS, 2010). The building sector has been making efforts to reduce carbon emissions for many years. However, there is still a long way to go to meet international expectations (Zhang and Wang, 2013). Given the large amount of new construction every year, it is necessary to significantly increase the proportion of low-carbon buildings (LCBs) (Zhen, 2012).

Comparing to conventional buildings, LCBs have many benefits (Hong et al., 2017). For example, they reveal a 25% decrease in emissions in terms of the reduction of life cycle CO_2 per unit area. If diverse production technologies and supply chains are further developed for low-carbon construction materials, carbon emissions would considerably decrease (Cho and Chae, 2016). LCBs also have social and economic advantages (Kennedy and Basu, 2013). For instance, tenants of LCBs display high levels of satisfaction, well-being, and productivity (Thomas, 2010). Similarly, buildings achieving low carbon ratings attract a higher rental premium compared to those without such ratings (Dawood et al., 2013). By virtue of these advantages, LCBs have been promoted in many countries/regions, including South Korea (Cho and Chae, 2016), United Kingdom (Zapata-Poveda and Tweed, 2014) , China (Zhen, 2012), etc.

Many studies concerning LCBs have been carried out. A scientific and comprehensive review of these studies could provide useful guidance for researchers and practitioners to understand the current state of play and to consider future directions. This study, therefore, uses a scientometrics method to conduct a comprehensive review of existing studies related to LCBs. It is a quantitative approach designed to reduce bias caused by manual review (He et al., 2017). This study aims to: 1) explore the knowledge hotspots (keywords co-occurrence network); 2) identify the significant knowledge topics (document co-citation network); 3) analyze the key knowledge domains (cluster analysis); and 4) confirm the knowledge structure of LCB research on the basis of knowledge hotspots, topics and domains.

2. Literature review

The concept of LCBs originated from the low carbon economy proposed by the British government in 2003 (Zhang et al., 2017) and mainly aims to reduce carbon emission and energy consumption (Dawood et al., 2013). Some scholars believe that LCBs are products to minimize energy consumption and carbon emissions. Some researchers believe LCBs require building products to be constructed with low-carbon technology and materials (Jiang and Li, 2010). Furthermore, some studies consider LCBs need to adopt low carbon methods during the entire life cycle of the building (Frank et al., 2015). Therefore, three characteristics pf LCBs can be summarized as: (1) improving energy performance and reducing carbon emissions; (2) using low carbon materials, techniques and renewable energy; and (3) considering the whole building life cycle (Zhang et al., 2017). However, several studies point that the development of LCBs is constrained by many factors. And many following studies have made great contribution made in addressing this lack.

Some scholars have confirmed some critical factors, including policy contents (Jiang and Tovey, 2009), local government support (Zhang and Wang, 2013), market demand (Zuo et al., 2012a), certification systems (Roh and Tae, 2016), and technology level (Li, 2008). Simultaneously, in order to maximize carbon reduction and minimize energy consumption, many researchers explore calculation and estimation techniques (Zhang and Wang, 2015). Some scholars also conduct the energy efficiency and carbon emission calculation form the perspective of building-related industries (Al-Ismaili et al., 2017), such as the manufacturing industry (Teh et al., 2017). Furthermore, carbon emissions and energy consumption during the whole life cycle have been examined, such as material production, on-site construction, transportation, operation, and final demolition and disposal (Hong et al., 2017). Reducing embodied energy and carbon in building materials production is often the first step in life cycle analysis (Gursel and Ostertag, 2016). Previous studies also suggest that technologies and design solutions are available that allow for cost-effective reduction of carbon emissions of 30-80% (Van der Heijden, 2016).

Given the overview of LCB research, many sub-areas of LCB knowledge have formed in recent years, ranging from coverage and definition, identification of influence factors and quantification of benefits, to measures that can achieve LCB outcomes. Collectively, they are the fundamental knowledge blocks of LCB research. However, most scholars tend to concentrate on one or two specific themes within a low carbon building sub-area (e.g. low carbon material and technology), which cannot systematically describe the wider research agenda (Zhang et al., 2017). Therefore, development of a systematical knowledge structure is necessary, suggesting a comprehensive review of existing LCB studies. The traditional review method has some limitations, produces manual bias, and is limited in terms of the number of articles that can be practically reviewed (Li et al., 2017). This study adopts a scientometrics method to review existing studies on LCBs and develop a robust knowledge structure to better support future research efforts.

3. Methodology

3.1 Research method

This study uses the scientometrics method to do a holistic review of research related to LCBs. Scientometrics refers to knowledge domain visualization or mapping (He et al., 2017). It is defined as the quantitative study of science, communication in science, and science policy, which can be used to map the structure and evolution of numerous subjects based on a large-scale scholarly dataset (Hood and Wilson, 2001). Various software have been used for presenting the outcomes of the scientometrics method (Xiang et al., 2017). Compared with other options, CiteSpace has more powerful visualization and stronger dynamic function (Chen et al., 2015a). It can visualize and analyze literature of a scientific knowledge domain, and it is strong in mapping knowledge domains through systematically creating various accessible graphs. Three analytical methods of CiteSpace are applied in this study, including the keyword co-occurrence analysis, the document co-citation analysis and clustering analysis.

3.2 Data collection

This study analyzes all the articles in the SCI-EXPANDED (Science Citation Index Expanded) and SSCI (Social Sciences Citation Index), which consists of the important and influential journals. Although the concept of LCBs originated in 2003, the early related studies can also make contribution to the domain's research, and hence the time span of selected papers was 1970-2017, the research topic used in literature searching can be selected as "low carbon" or "low-carbon" + "building or construction or housing". The searching results include 1,354 records. However, in this study, only journal articles were selected for analysis, while book chapters and proceeding papers were excluded. Additionally, those research papers obviously irrelevant to LCBs (e.g., archaeology, astronomy, cultural studies, etc.) were also excluded. Finally, a total of 378 bibliographic records were identified.

4. Results

4.1 Keyword co-occurrence analysis

Keywords are the essence and refinement of the research contents. Keyword analysis can help identify critical research key points in LCB-related studies. Therefore, based on the contributions and frequencies of keywords on LCBs (Chen et al., 2015b), the visual knowledge map of the keywords co-occurrence network is drawn by CiteSpace and shown in Figure1. It consists of 373 nodes and 763 links. Each node represents a keyword and the node size represents the frequency with which a keyword occurred in the dataset. Meanwhile, the links between the keywords denote the occurrence established through the co-occurrence in the articles (Zhao, 2017). This network can represent the frontiers and central tendency in the field of LCB research.

The results show that the most frequently used term is energy. The energy used in buildings' life cycle account for 40% of global energy consumption (Van der Heijden, 2016). Therefore, improving energy efficiency (Wong et al., 2015), reducing energy consumption (Dawood et al., 2013) and implementing some other energy conservation-related strategies may be the most effective and available measures to reduce carbon emission in buildings (Azzouz et al., 2017). Performance is the second largest research hotspot (Shea et al., 2012). This topic mainly refers to the building system performance (Lehmann, 2013) and environmental sustainability (Chen and Ng, 2016). Building performance includes energy system performance (Wang et al., 2016), building structural performance (Kim et al., 2017) and materials performance (Liu et al., 2017). Furthermore, in order to improve environmental sustainability, the success of construction projects also needs awareness of the environmental impacts caused by buildings, including indoor environmental quality, waste and pollution, ecology and performance of on-site management (Chen and Ng, 2016). Life cycle assessment (LCA) is the third largest research hotspot. LCA is an analytical methodology for a systematic evaluation and identification of the impacts through all stages of building life cycle (Toller et al., 2011). The cost and benefit are the important items in building life cycle assessment (Timmons et al., 2016), from the perspective of environmental performance, some scholars consider that life cycle thinking should be part of the assessment of energy consumption, carbon emissions and other impacts (Pomponi et al., 2015).

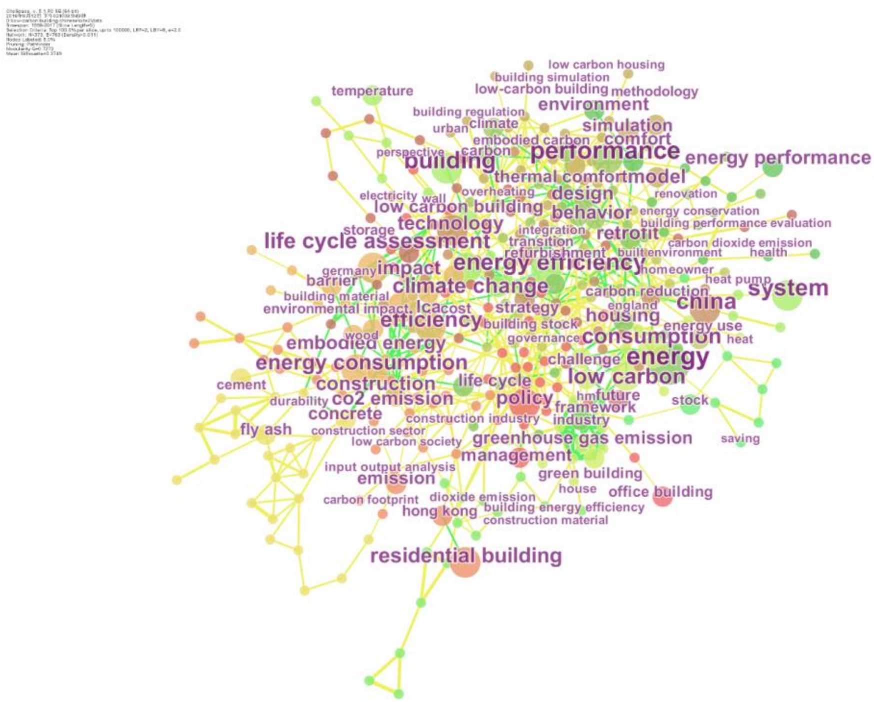

Figure 1: Keywords Co-Occurrence Network of LCB Research

4.2 Document co-citation analysis

Figure. 2 shows the overview of the document co-citation network generated with 353 nodes and 619 links, visualized and analyzed by CiteSpace. CiteSpace divides the timeline (1970–2017) into a series of time slices (each time slice equals one year). The top-cited publications (top 50 publications) during each time slice are selected for subsequent analysis. Every node represents a cited reference, and the links connecting the nodes represent co-citation relationships. Furthermore, larger node size suggests that the publication is cited more frequently and implies that the paper is an important one in LCB knowledge.

Based on Figure 2, the problem of energy consumption in buildings is an important research area. The type of energy (e.g. electricity and fuel) will produce the carbon emission or greenhouse gas emission directly or indirectly. (Gram-Hanssen, 2010). The results show that the estimation and calculation of the carbon emission and energy consumption is a very important research item, and all phases of the life cycle have to be considered. (Gustavsson et al., 2010, Chau et al., 2015). In order to deal with the vast amount of carbon emission and energy consumption, construction industry has applied many practices and schemes of carbon emission (Osmani and O'Reilly, 2009, Zuo et al., 2012b). Other best practices also provide a source of reference. For example, Zuo and Zhao (2014) and Hakkinen and Belloni (2011) conducted studies on green building and sustainable building. These two building typologies include broad definitions of sustainability, incorporating economic and social factors (Zuo and Zhao, 2014). The research on green/sustainable building can be considered as an outstanding reference on research methods and contents. International certification and evaluation systems for green building are relatively mature, such as the Leadership in Energy and Environmental Design (LEED) (Lai et al., 2016).

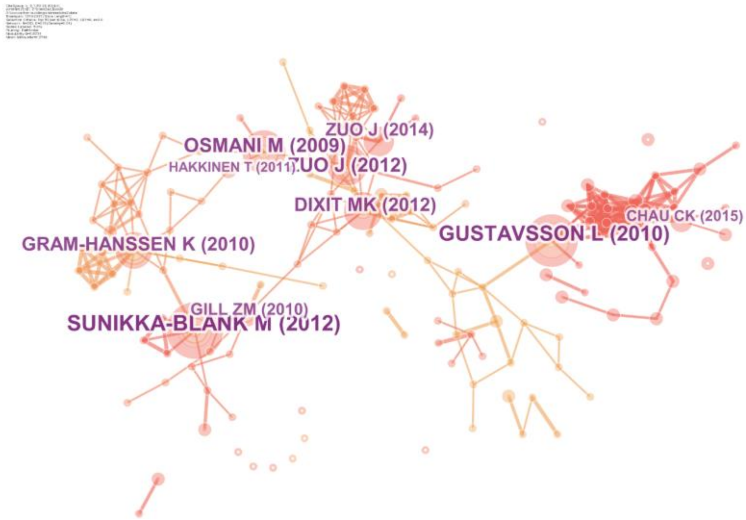

Figure 2: Document Co-Citation Network of LCB Research

4.3 Clustering analysis

The keyword co-occurrence network can provide further insights into LCB research. As a mathematical and statistical method, cluster analysis is used to identify the latent semantic themes within the textual data. It employs a set of algorithms to convert unstructured text into structured data objects to detect research patterns for the discovery of knowledge (He et al., 2017). Three statistical methods, including the log-likelihood ratio (LLR) test, term frequency-inverse document frequency (TF∗IDF) and mutual information (MI) tests, can be used for this process (Zhao, 2017). Figure 3 shows the 15 labeled clusters with keywords and their relative importance via a TF∗IDF test (with the largest cluster numbered as #0 and the smallest cluster numbered as #14). The size of a cluster is decided by the total number of keywords that the cluster contains (the largest cluster has 36 publications and the smallest has 9).

The most significant cluster is the industrial symbiosis. The studies are related to relative industry development, best practice experience, policy and regulation, which can provide important examples of LCB development from the perspective of practice. Industrial symbiosis emphasizes the need to enhance resource efficiency, reduce waste generation and GHG emissions via material, energy, and by-products exchange between different processes and industries (Sun et al., 2017). With urban industrial symbiosis design, some energy sources and wastes can act as the sources for the substitution of raw materials and fossil fuels in other companies or sectors. The second most significant cluster is related to the energy efficiency. Improving energy efficiency in existing buildings is often considered to be one of the most cost-effective measures for cutting down on carbon emissions and considerable energy saving potential has been demonstrated in different countries (Sunikka, 2006). The third most significant cluster refers to ventilation, which targets optimizing the LCB design. Reasonable building design not only can ensure a comfortable indoor environment in the most efficient way, but also improve building energy conservation performance (Mora-Perez et al., 2016). Favorable displacement ventilation can maintain indoor air quality (Liu et al., 2014), and it is also found that the natural ventilation design can improve the building energy performance by reducing cooling energy consumption (Mora-Perez et al., 2016). CO_2 emission is doubtless a significant research area. Based on the estimation of carbon emissions over different building structures (e.g. residential building and office building), the quantitation results of carbon emission are discrepant (Wen et al., 2016). Meanwhile, over the whole life-cycle (e.g. embodied carbon emission, operations stage carbon emission, demolition and reclamation stage carbon emission), the carbon emission from different stages is also diverse (Chau et al., 2015).

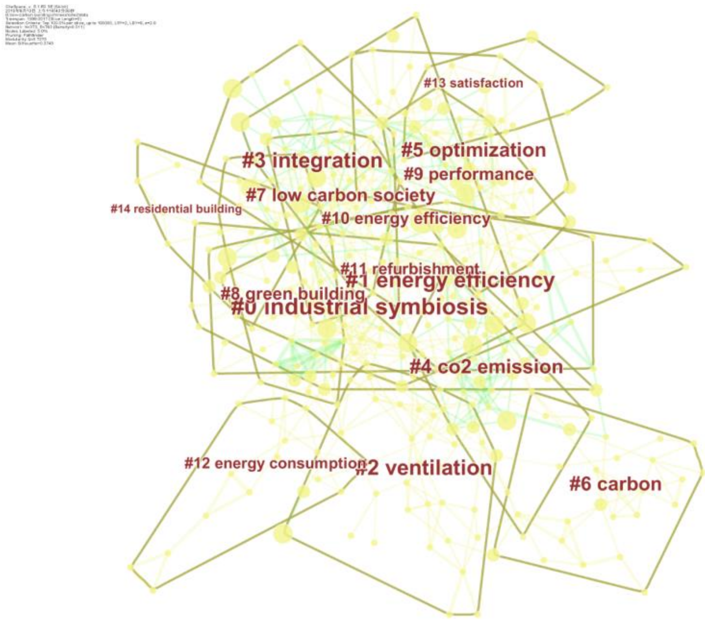

Figure 3: Clusters of LCB Research

5. Discussions

A systematic and comprehensive knowledge structure of LCBs is critical for both researchers and practitioners. There are many factors affecting the implementation of LCBs, including macro-level management, the development of low-carbon theories, low-carbon technologies, low-carbon facilities, the structure of building energy consumption, and LCB project practice (Shi et al., 2015a). Therefore, there is a need to give a holistic review of existing studies related to LCBs at a macro-level, which can provide guidance for future research. This study uses a systematic and quantitative scientometrics method for clearly visualizing and interpreting knowledge structure of LCB-related research. The findings of hidden connections can be integrated to form a knowledge structure of LCB research, as shown in Figure 4. Figure 4 shows that the low carbon building knowledge structure has five major components, including policy and practice, assessment/evaluation, building design, building materials and technology innovation. Meanwhile, the sub-topics in each component were also identified.

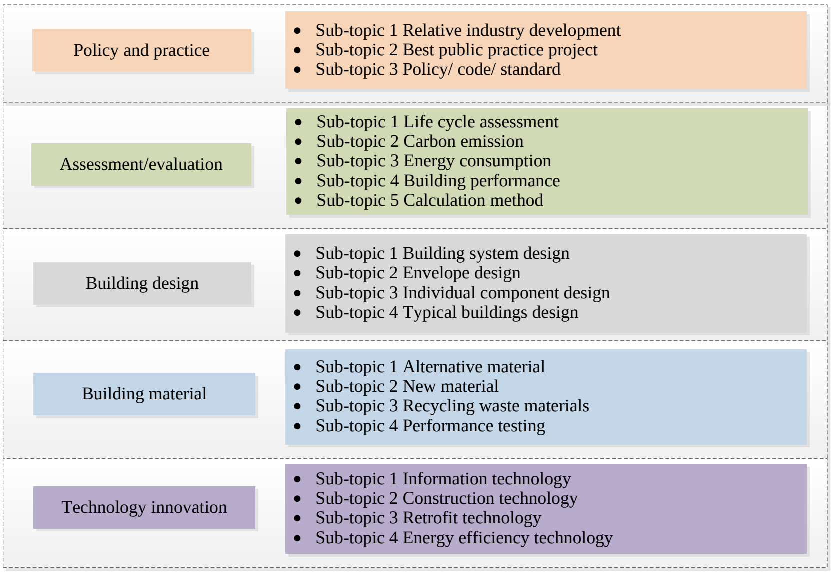

Figure 4: Knowledge Structure of LCB Research

6. Conclusions

With the increasing trend of CO_2 emission, LCB is considered important for carbon reduction and energy saving. The significance of LCBs has been studied by many researchers. It is necessary to review the existing LCB research and knowledge structure. In this study, a comprehensive literature review of low carbon building was conducted using the scientometrics method. A total of 378 LCB-related articles were identified in this study, and analyzed through keyword co-occurrence network analysis, document co-citation analysis, and cluster analysis. Finally, a knowledge structure of LCB research was presented. This study helps the various stakeholders to understand the current status of LCB research and development. The results can also be used to guide to inform future research and development.

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