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A scientometric analysis and visualization of global green building research

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Abstract

In this paper, the first inclusive scientometric review of global green building research (GGBR) is presented. The aim of this review study is to systematically analyze and visualize the state-of-the-art of the GGBR. To this end, a quantitative method – science mapping – was employed to analyze 6,867 related bibliographic records retrieved from Scopus. The research findings are instructive in identifying and understanding trends and patterns, including core research areas, journals, institutions, and countries, and how these are linked, within the existing body of literature on green building (GB). They also assist in recognizing the gaps and deficiencies in the current GGBR and thus useful and promising directions for future research. This research has implications for journal editors, practitioners, policy makers, researchers, and research institutions, e.g., universities. It can help these stakeholders make vital contributions to developing and accruing intellectual wealth to the GB area, while providing them with a detailed understanding of the trend and status quo of the GGBR.

Keywords: Green building; Sustainability; Research; Scientometrics; Review.

1. Introduction

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Improving the deteriorating environment and protecting natural resources have become a global focus recently (Jiang et al., 2018). In 2011, the rate of global energy use hit 8.92×10^{12} kg of oil equivalent per year – a rate projected to increase to 14×10^{12} kg of oil equivalent per year by 2020 (Allouhi et al., 2015). Despite its central role in boosting economic development and accelerating the achievement of urbanization, the construction industry creates several environmental problems while consuming a great deal of resources. Buildings are responsible for about 40% of total energy consumption and one-third of total greenhouse gas emissions in the world every year (WorldGBC, 2013; IPCC, 2014). This underscores the critical need to implement and achieve sustainable development in the construction industry, resulting in the introduction of the green building (GB) concept (Kohler, 1999). Kibert (1994) defined sustainable construction as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles"; while the USEPA (2016) defined GB as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation, and deconstruction." The present study is focused on reviewing the literature concerning GB. GB is an effective measure to implement sustainable development in the construction industry.

Thus, GB has received great attention from both industry practitioners and researchers (Darko and Chan, 2016), with a concomitant rise in the number of related research works and publications (Venkataraman and Cheng, 2018; Ulubeyli and Kazanci, 2018). This surge in GB research presents danger, as it makes it tough to grasp the status quo of the body of knowledge, posing a major risk of neglecting essential questions and areas for research and practice improvement (Hosseini et al., 2018a). In order to solve this scientific problem, undertaking a rigorous analysis of the domain is necessary. Yet, this has not been adequately addressed in the present research area. The extant GB review studies (Zuo and Zhao, 2014; Zhang, 2015; Darko and Chan, 2016) have been qualitative and based upon manual appraisals, which have been criticized for their lack of reproducibility and proneness to subjective biases, which could reduce their reliability (Hammersley, 2001; Yu and Liao, 2016). Markoulli et al. (2017) indicated that qualitative, manual reviews examine the "trees", but do not provide a wide overview of the "forest". Moreover, as the global GB research (GGBR) addresses several different aspects and issues of GB, most review studies have focused on specific, limited aspects of GB. For example, whereas the review studies by Falkenbach et al. (2010) and Darko et al. (2017) focused on the drivers for GB, that by Darko and Chan (2017) focused on the barriers to GB. As for the more recent bibliometric review of the GB literature (Zhao et al., 2018), it provided a picture of the literature while having a number of limitations. Firs, it excluded a significant portion of the body of literature because it was limited to the literature published from 2000 to 2016. As GB research has been around since the 1970s (see Fig. 1), focusing on only the "2000 to 2016" literature is insufficient. Second, while identifying research areas that need more attention, these were based upon subjective deductions. Third, it does not address the core question of what could be learnt from all of this? Simply put, the available bibliometric review of the GB literature did not move from describing the data to interpreting and bringing out the significance of the findings for diagnosing and recommending future research priorities. Although collective description of the extant body of knowledge may be beneficial to the world of practice, the industry is also interested in knowing exactly what research works must be done to bring more practical benefits (Hosseini et al., 2018a). In view of what has already been completed, the industry wants to understand what more could be done.

Due to the limitations of the previous GB review studies, they do not afford a full picture of the state-of-the-art of the GGBR from its advent to the present. That is, a study that affords an inclusive picture and understanding of the trend and status quo of the GGBR in its entirety is still missing. The present study is an attempt at addressing this gap through presenting an inclusive scientometric review of the GGBR. A quantitative method – science mapping – is utilized to analyze the existing intellectual core and landscape of the global body of knowledge on GB. In turn, this study identifies the scope and quality of the existing body of GB knowledge while also detecting omissions and deficiencies. The research findings contribute to the global body of GB knowledge by providing a detailed understanding of the current state of the GGBR and identifying where best to focus future research efforts. They can also contribute to practice by serving as a valuable and updated reference for supporting policy makers' and practitioners' GGBR planning and funding efforts.

2. Research methodology

The present study used the science mapping method to analyze the GGBR. Science mapping – "a generic process of domain analysis and visualization" (Chen, 2017) – aims at detecting the intellectual structure of a scientific domain. The science mapping method is helpful for visualizing significant patterns and trends within a large body of literature and bibliographic data (Cobo et at., 2011). It allows researchers to make literature-related discoveries that may not be possible through other methods (Su and Lee, 2010). A science mapping-based study typically applies a bibliometric analysis technique or scientometric analysis technique (Hosseini et al., 2018b). While bibliometric analysis focuses upon the literature per se; scientometric analysis offers a broader approach, that encompasses bibliometric tools and data, to analyze the literature and its outputs to recognize the domain's potentially insightful patterns and trends (Hood and

Wilson, 2001). Hence, scientometric analysis technique was adopted in this study. Following Börner's (2010) suggestion, the research methodology was designed to cover the following phases – science mapping tools selection; data collection and analysis; visualization; and presentation, interpretation, and discussion of findings.

2.1. Science mapping tools selection

Various science mapping tools for analyzing and visualizing structural, dynamic, and temporal patterns and trends in scientific literature of a knowledge domain exist (Cobo et al., 2011). Each tool has its own strengths and capabilities regarding the kinds of analyses it can perform. Thus, to thoroughly examine any domain, appropriate use of different tools for different kinds of analyses is necessary. For this research, after analyzing various science mapping tools, VOSviewer, Gephi, and CiteSpace were selected. VOSviewer, a software tool, affords the basic functionality required for producing, visualizing, and exploring bibliometric networks (Van Eck and Waltman, 2018). Gephi, a leading, open-source "all kinds of graphs and networks" exploration, visualization, and manipulation software tool, provides convenience for gaining detailed insight into the information attainable from a particular graph or network (Bastian et al., 2009). CiteSpace, a software tool "developed to meet the needs for visual analytic tasks of science mapping" (Chen, 2017), affords opportunity for addressing important questions about a knowledge domain, such as what the major research areas are, and how these areas are linked (Chen, 2014). More information on the technical applications of VOSviewer, Gephi, and CiteSpace can be found in Van Eck and Waltman (2010), Gephi (2017), and Chen (2014), respectively. In this study, the various analyses conducted with these tools can be understood in this paper's later sections.

2.2. Data collection

Bibliographic data collected from Scopus, rather than those from other databases like the Web of Science, Google Scholar, and ResearchGate, were analyzed in this study. The basis behind this is that compared to the other databases, Scopus possesses a wider range of scientific publication coverage (Zhao et al., 2018). Likewise, Scopus has a relatively faster indexing process, increasing the possibility of more current publications retrieval (Meho and Rogers, 2008). It has been widely used in previous review studies as well (Hosseini et al., 2018a, b). Following the earlier review studies (Darko and Chan, 2016; Zhao et al., 2018), the terms green building, green construction, sustainable building, sustainable construction, green technology, high-performance building, and high-performance construction were used to retrieve the bibliographic data. It should be noted that while this study does not intend to include all potential terms in the area, it is arduous to include all potential terms in one study (Darko and Chan, 2016). Therefore, including other terms, such as embodied energy, indoor air quality, and thermal comfort, is possible if one would like to improve this research in the future. No "date range" limit was set, i.e., the date range was set to "published all years to present". As for the "document type", it was limited to "article". The rationale for limiting the document type to articles is that, for science mapping purpose, journal articles represent the most influential and reputable research (Santos et al., 2017) and have been classified as "certified knowledge" (Ramos- Rodríguez and Ruíz- Navarro, 2004). Moreover, the fact that many previous review studies in the construction management field are based solely upon journal articles may infer consensus in the profession on the preferability of picturing the intellectual structure of a domain based on journal articles (Santos et al., 2017). Similarly, although it may be useful to include all document or literature types on the topic, it should be highlighted that such move is "challenging and costly" (Hosseini et al., 2018b). Consequently, such move was not made since the literature in academic journals could adequately serve this study's purpose.

As of October 31, 2018, 6,867 publications were found, for which all bibliographic information were exported from Scopus, forming this study's dataset.

2.3. Scientometric techniques

According to Chen (2017), scientometric techniques involve keywords co-occurrence analysis, author co-citation analysis, document co-citation analysis, etc. In this study, science mapping was conducted within two stages. The first stage involved constructing networks through keywords co-occurrence analysis, citation burst analysis, outlets direct citation analysis, and co-authorship analysis, as expounded in the next section. The second stage involved generating maps for mining useful information from network measures, which display "the conceptual, intellectual, or social evolution of the research field, discovering patterns, trends, seasonality, and outliers" (Cobo et al., 2011).

3. Analysis and results

3.1. Wave of GGBR

The first GB-related study in the dataset turned out to be the research by Doss and Marrs (1974), published in *Adhesives Age*, wherein high-performance construction sealants' characteristics and formulation were analyzed. Fig. 1 indicates the trend in GGBR publications over the period from 1974 to 2018. Compared to the 20th century (1974–2000), the 21st century (2001–2018) has seen more GB research publications. This infers growth in GGBR in recent years and is consistent with a rapid growth in practical GB implementation (USGBC, 2018). This momentous growth in GGBR in the 21st century and the possible reasons that underpin it were identified and discussed by Darko and Chan (2016). As indicated earlier, the literature search was conducted on

October 31, 2018. Consequently, publications that may appear in Scopus after this date might not have been captured. It is therefore worth noting that the number of publications in 2018 (713 – Fig. 1) may increase at the end of the year; while the approach of limiting the review to publications that could be retrieved on the literature search date was adopted from Li et al. (2014). Moreover, it is acknowledged that the number of publications for the period 1974–1994 is relatively small. Future review studies may target including more publications from this period, which could be achieved through modifying the literature search terms as directed in section 2.2.

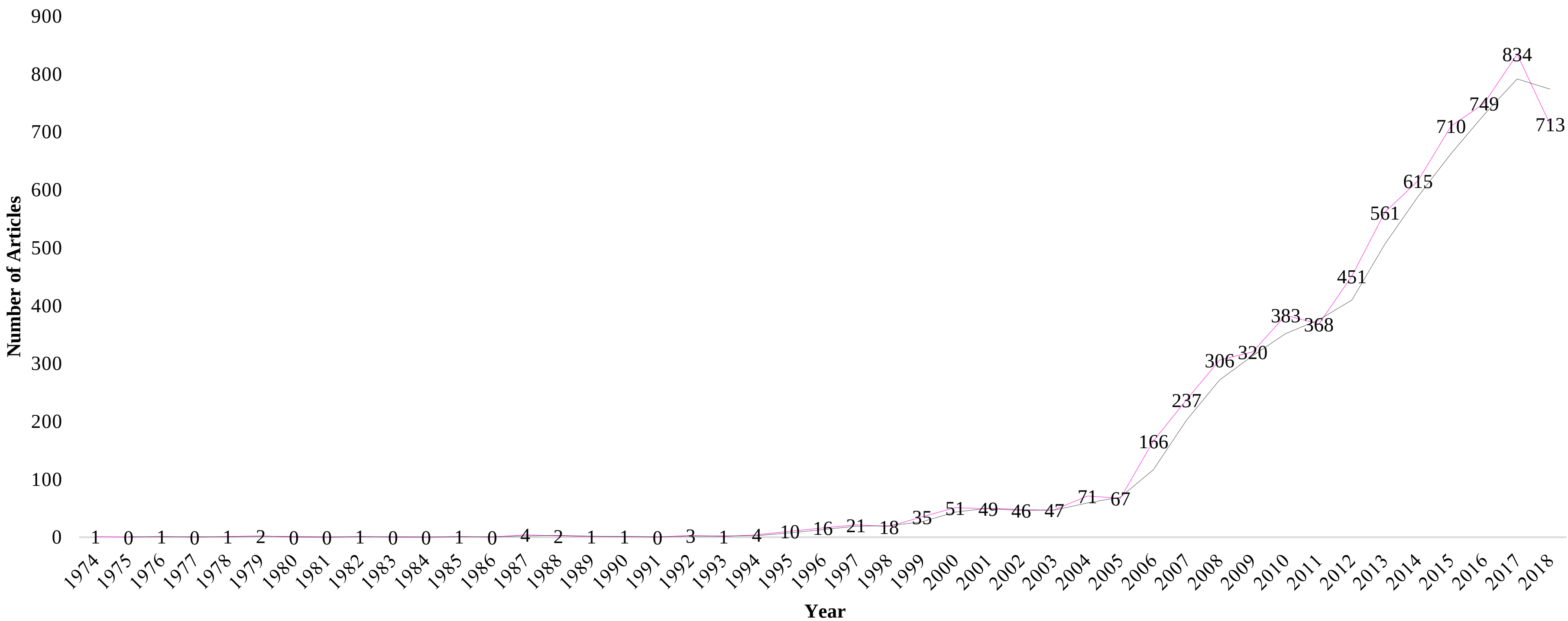
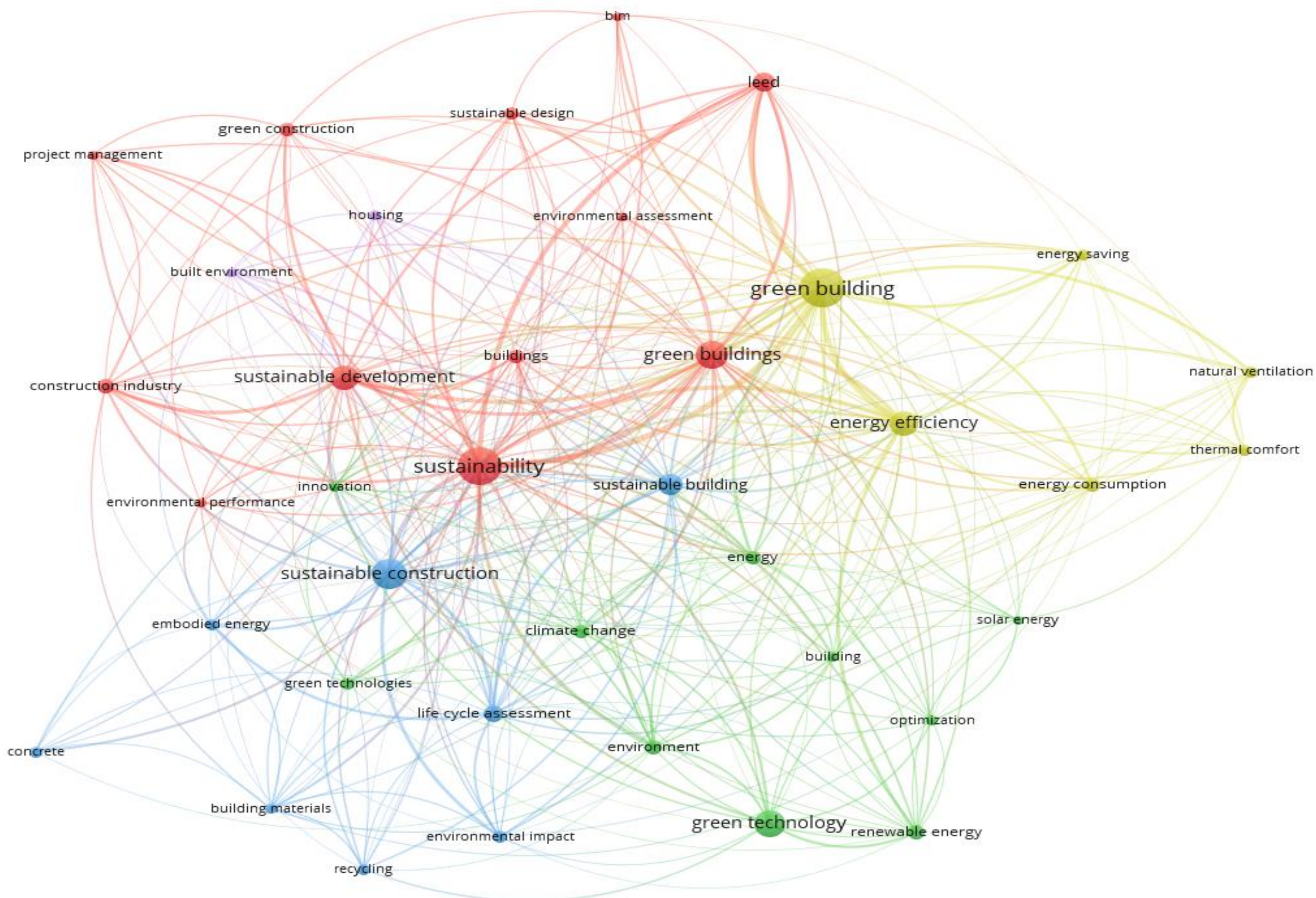


Fig. 1. Trend in GGBR publications from 1974 to 2018 (as of end of October).

3.2. Structure of the global body of GB knowledge

3.2.1. Main research areas: keywords co-occurrence analysis and citation burst analysis

Analyzing keywords provides an opportunity for discovering main research areas (Shrivastava and Mahajan, 2016). According to Su and Lee (2010), "keywords represent the core research of a paper". A keywords network offers a good picture of a knowledge domain, providing insight into the topics covered and how these topics are intellectually associated and organized (Van Eck and Waltman, 2014). Hence, a keywords co-occurrence network was produced using VOSviewer 1.6.8 software, based on the bibliographic data retrieved from Scopus. In order to achieve a reproducible and readable picture of the keywords, author keywords, rather than all keywords, were used. Based on the fractional counting methodology, a total of 14604 keywords were extracted from the dataset. For the "minimum number of occurrences" a keyword must have to be included in the network, a value of 30 was selected; an inclusion criterion met by 42 keywords. After excluding generic terms (such as data analysis and survey), the resultant network consisted of 38 nodes and 356 links, as displayed in Fig. 2, depicting the main areas of the current GGBR. The strength of the link amongst two keywords is computed based on the number of articles in which the keywords appear together, reflecting the association of their respective research areas (Van Eck and Waltman, 2018); and the stronger the link, the thicker the line that displays the link in the network visualization.



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189 **Fig. 2.** Main areas of GGBR (co-occurrence network of keywords).

Measuring the centrality of nodes is the most reliable and simplest method to recognize what is important in a network (Prell, 2012). Centrality can be measured by computing degree centrality, which reflects the number of links a node has to other nodes (Hosseini et al., 2018b). Calculating importance based on the number of links aids to understand the influence of a node on other nodes. Regardless of the value and direction of all existing links, degree centrality is computed using the following equation (Prell, 2012):

$$D_i = \sum_{i=1}^{n} X_{ij}$$

where D_i = degree centrality value for node i; X_{ij} = sum of all links between node i and node j; and n = total number of nodes in the network. The network created using VOSviewer (Fig. 2), was submitted to Gephi 0.9.2 for calculating the centrality of nodes. The analysis results are shown in Table 1. The main research areas were ranked based upon the degree centrality values. The higher the degree centrality value, the more influential the research area. However, where two or more research areas have equal degree centrality value, the one with the highest weighted degree value is ranked higher. Weighted degree is a modified version of degree centrality that takes into account the average mean of the sum of the strengths of the links among all the nodes within the network.

Table 1
Relative influence of GGBR areas.

Research area	Degree centrality	Weighted degree centrality	Relative influence	First cited[a]
Green building	35	242	1	1990
Sustainability	34	270	2	1996
Sustainable construction	33	136	3	1996
Green buildings	32	131	4	1990
Energy efficiency	30	147	5	1996
Sustainable development	30	131	6	1995
Sustainable building	27	75	7	1996
Climate change	24	42	8	1995
Life cycle assessment	22	68	9	1996
Energy	22	45	10	1985
LEED	21	96	11	1999
Environment	21	52	12	1994
Construction industry	20	57	13	1994

Buildings	20	49	14	1976
Renewable energy	19	46	15	1996
Embodied energy	17	34	16	1998
Building materials	17	30	17	1978
Innovation	17	29	18	1995
Energy consumption	16	44	19	1996
Environmental impact	16	37	20	1992
Sustainable design	16	32	21	1996
Energy saving	16	31	22	1999
Green construction	16	30	23	1982
Environmental assessment	15	20	24	1992
Green technology	14	46	25	1988
Building	14	27	26	1976
Housing	14	26	27	1995
Built environment	14	25	28	1998
Environmental performance	14	22	29	1982
Optimization	14	20	30	1994
Natural ventilation	13	27	31	1999
Recycling	13	21	32	1994
Solar energy	13	17	33	1999
Thermal comfort	12	24	34	1997
Project management	11	29	35	1996
Green technologies	11	19	36	1998
BIM	10	21	37	2005
Concrete	9	16	38	1994

[a]When the term was first cited in the GB literature (according to Scopus).

The ranking of the research areas (Table 1) and the relatedness of the areas (as indicated in Fig. 2) reveal several key findings, highlighting gaps and deficiencies within the global GB literature:

- Certain research areas have remained under-researched and isolated. Of particular interest are: concrete, BIM (building information modeling), green technologies, project management, and thermal comfort – all of which had degree centrality values well below those of the top-ranked research areas. Concrete is a major construction material worldwide. Therefore, improving the sustainability of concrete production could play a pivotal role in global sustainable development (Bilodeau and Malhotra, 2000). However, within the current GGBR, this has received very little attention. Substituting "virgin" materials (such as Portland cement) with recycled or sustainable materials (such as fly ash) in concrete (Sandanayake et al., 2018) should draw GB experts' and researchers' attention. The limited attention to BIM in the GGBR concurs with the findings of Darko and Chan (2016) and Zhao et al. (2018) and might be because artificial intelligence (AI) and automation have yet to be fully integrated into the main body of GGBR. Green technologies (e.g., natural ventilation technology and solar energy technology) are key to achieving GB, from the technological perspective (Zuo and Zhao, 2014). Nevertheless, as a concern for practitioners and researchers (Aktas and Ozorhon, 2015; Bubbs, 2017), it remains unclear which innovative technologies can be utilized to construct and achieve highly efficient GBs in different contexts. Project management issues in GB (such as project manager competency, knowledge, and skills; project success; health and safety; productivity; and risk management) have also been largely overlooked in the existing GGBR (Hwang and Ng, 2013; Sang et al., 2018). In spite of thermal comfort being one of the well-known GB benefits, the GB literature is still in need of more studies that assess: (1) the performance of actual GBs in terms of ensuring occupants' thermal comfort (Fedorczak-Cisak et al., 2018); and (2) how to technologically deliver GBs that are effective in offering this benefit.

- Additionally, areas such as recycling, optimization, and building materials are not of noticeable importance within the current GGBR. Consequently, more research should be done to address the optimization of processes and intelligent use of building materials and resources within the industry, which are issues central to sustainability aspects such as waste reduction. BIM affords great potential for optimizing processes (Ellul et al., 2017). However, as established in Fig. 2, BIM and optimization are not linked and are widely apart in the existing body of GB knowledge. This missing and unconfirmed association among BIM and optimization in the GB arena invites further investigations, and so does promoting "reuse and recycling" (WorldGBC, 2018a).

- Moreover, the presence of LEED (Leadership in Energy and Environmental Design) as an area and the absence of other GB rating systems underline the fact that the GB literature has placed more focus on LEED implementation, while it shows serious disregard for the development and diffusion of other GB rating systems worldwide. It is critical for research to direct more attention to the development and widespread application of country or context-specific GB rating systems because: “different countries and regions have a range of characteristics such as distinctive climatic conditions, unique cultures and traditions, diverse building types and ages, or wide-ranging environmental, economic, and social priorities – all of which shape their approach to GB” (WorldGBC, 2018b).
- Furthermore, the presence of building as an area and the absence of other construction project categories highlight that the GGBR has predominantly explored the building sector; thus, there is inadequate research about the use of green innovations and concepts in infrastructure projects (Ghoddousi et al., 2018). Even in this current state of the GGBR, more attention has been paid to the sustainability of housing (Fastofski et al., 2017; Hu et al., 2018) than that of other building types, such as educational, hospital, and commercial buildings, as evidenced by the presence of housing as an area and the absence of other building types in the network in Fig. 2.
- Also, the terms environment, environmental impact, environmental assessment, environmental performance, energy, energy saving, energy efficiency, energy consumption, embodied energy, renewable energy, and climate change together constitute a considerable portion of the body of GB literature, as indicated in Fig. 2. This implies that the environmental aspect of sustainability of GB has received special attention, whereas the social and economic aspects have been largely ignored, in the existing GGBR. This finding is

consistent with the observations of Zuo and Zhao (2014) and Zhang (2015). It may be because "traditionally the focus of GB studies is placed on environmental aspect of sustainability" (Zuo and Zhao, 2014, p. 273). It further elucidates the earlier observation concerning the limited attention to thermal comfort as an area of GGBR. In addition, it is reinforced by the dominance of environmental sustainability issues within Fig. 3, which shows the results of citation burst analysis conducted using CiteSpace 5.3.R3. Citation bursts afford evidence of which keywords have frequently been cited within the literature within a particular time period; namely fast-growing topics or topics that are associated with surges in citations (Chen, 2014). In other words, citation bursts offer insight into topics that have received significant attention from the scientific community. From the dataset, a total of 104 keywords had citation bursts. Fig. 3 shows the top 25 (default value) keywords with the strongest citation bursts; with ventilation (burst strength, 21.02; 1997-2009), environmental protection (19.83; 1995-2007), and environmental impact (18.41; 1996-2006) having the strongest bursts amongst the 25 keywords. This infers that these were the hot topics in the respective years. The hot topics in the recent years include energy, sustainable design, rating systems, and waste management.

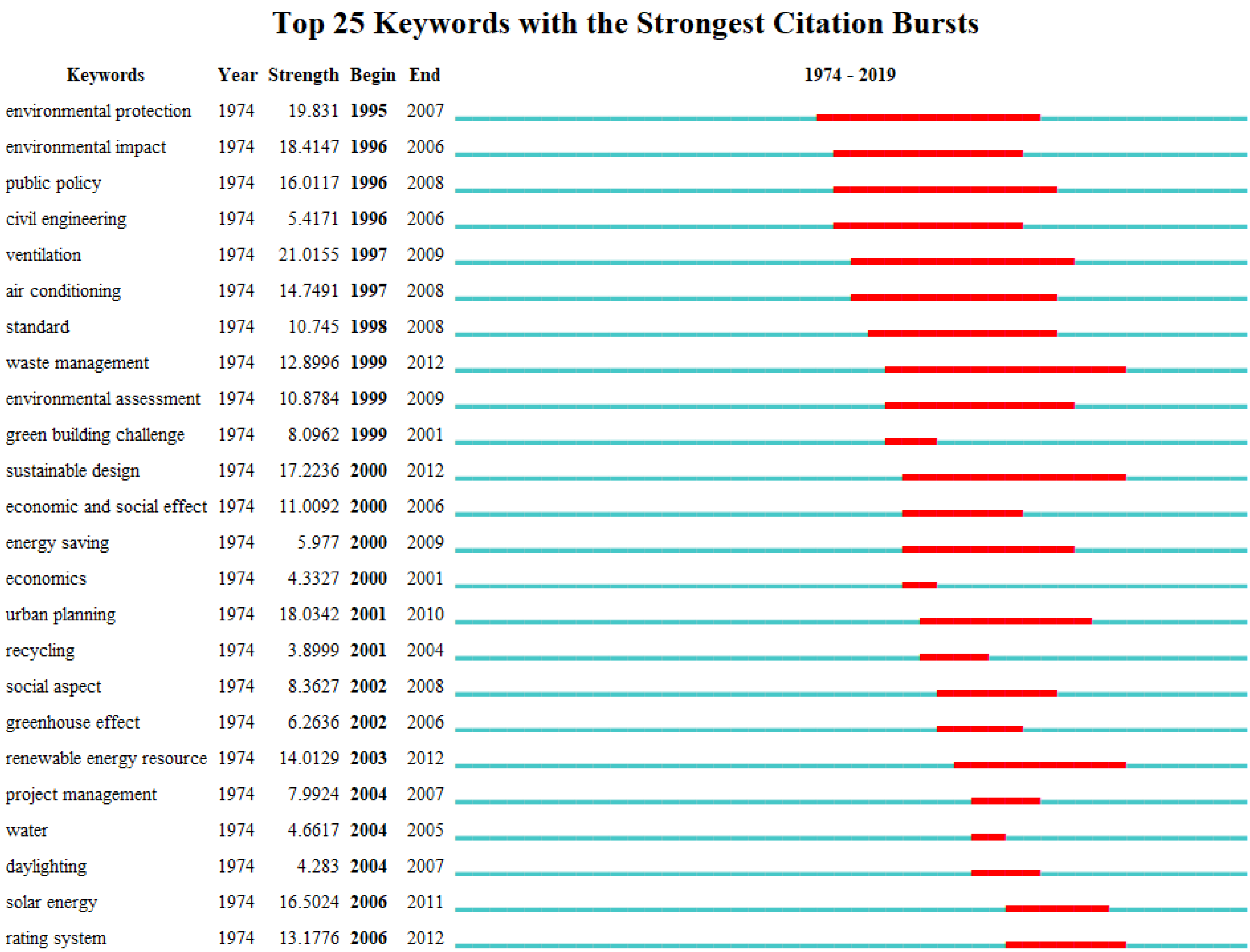

Fig. 3. Top 25 keywords with the strongest citation bursts in the GB literature (1974-2018).

3.2.2. Top research outlets: outlets direct citation analysis

Many studies have stressed the importance of analyzing the academic journals in any scientific field (Serenko, 2010). Such analysis may be of immediate use to readers in finding the best sources of information, and to authors in finding journals that may be best suited for publishing their works. Also, it may help journal editors in making relevant adjustments to the goals of their journals, and institutions and libraries in optimizing the allocation of resources to invest in journals (Hosseini et al., 2018a). In this study, a direct citation analysis of outlets was conducted to provide evidence of the prominence of the academic journals that publish GGBR.

VOSviewer was employed; the type of analysis was “citation”, and the unit of analysis was “sources”. Also, the “minimum number of documents of a source” and the “minimum number of citations of a source” were both set to 20. Of the 1992 sources identified, 31 met these thresholds and were included in the resultant network, which consisted of 268 links amongst the 31 outlets. The network was visualized using Gephi, as displayed in Fig. 4.

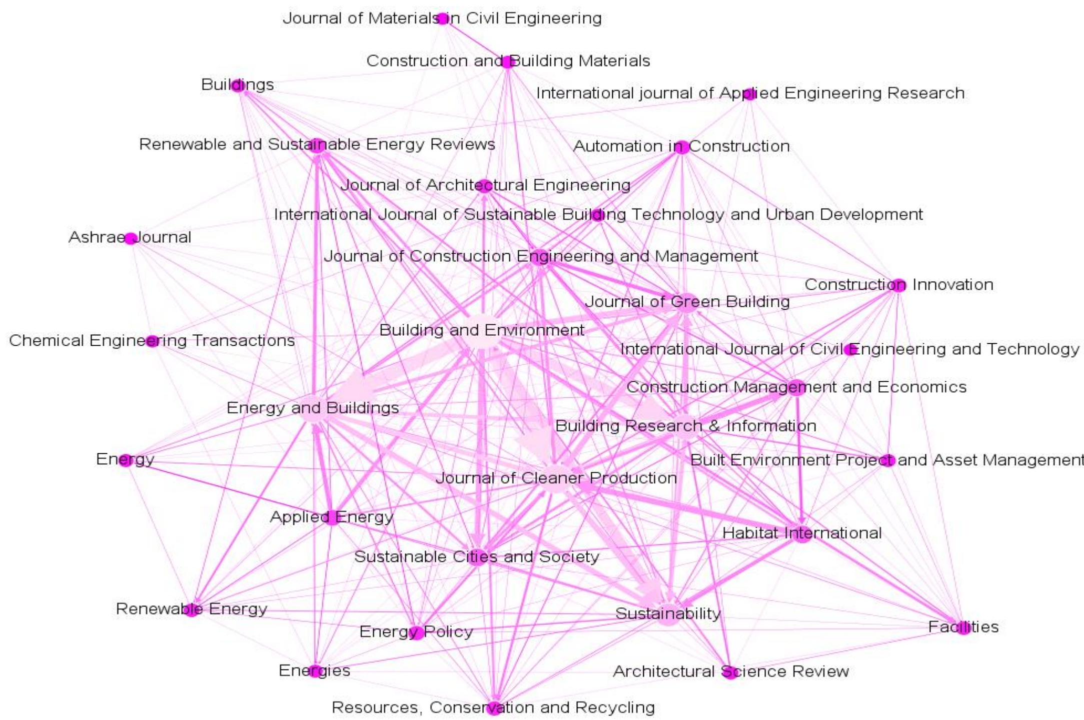

Fig. 4. Network of prominent outlets for publications on GB.

Weighted degree has been widely used to measure the level of influence of nodes in the control of information flow across networks (Prell, 2012). In this study, weighted degree values were used for resizing and recoloring the nodes inside Fig. 4, with lighter and larger nodes representing higher weighted degree values. Table 2 displays the most influential outlets within Fig. 4; that is, the top 15 outlets for GGBR, ranked based on their weighted degree.

Table 2
Top 15 outlets for GGBR.

Rank[a]	Outlets	Weighted degree value
1	Building and Environment	596
2	Journal of Cleaner Production	430

3	Energy and Buildings	388
4	Building Research & Information	349
5	Sustainability	286
6	Journal of Green Building	237
7	Sustainable Cities and Society	159
8	Habitat International	157
9	Journal of Construction Engineering and Management	147
10	Construction Management and Economics	142
11	Applied Energy	110
12	Renewable and Sustainable Energy Reviews	103
13	Energy Policy	70
14	Resources, Conservation and Recycling	69
15	Journal of Architectural Engineering	68

[a]Ranking based upon weighted degree values.

The results show that the most influential outlet for GGBR is *Building and Environment* (which had the highest weighted degree value of 596). There is significant information flow (via citations) from this journal toward *Journal of Cleaner Production*, *Energy and Buildings*, *Building Research & Information*, and *Sustainability* (as exemplified in Fig. 4), which are the second tier of influential outlets in the area (Table 2). These five outlets may consequently serve as the key reference points for GGBR. And the topmost standing of *Building and Environment* could be justified by the earlier finding that the existing GB literature has principally focused on the environmental aspect of GB, which fits perfectly within the "aims & scope" of *Building and Environment* (Elsevier, 2018). According to Knight and Steinbach (2008), the most important factor in choosing a journal is the "fit" between the paper and the journal.

3.3. Scientific collaboration networks in GGBR: co-authorship analysis

Knowledge of the current scientific collaboration networks within any research domain can (1) promote access to specialties, funds, and expertise, and (2) increase productivity (Hosseini et al., 2018b). Ding (2011) showed that such knowledge is core to furthering academic collaboration and communications. According to Glänzel and Schubert (2005, p. 257), "almost every aspect of scientific collaboration can be reliably tracked by analyzing co-authorship networks". Hosseini et al. (2018a, p. 8) mentioned that "co-authorship is shorthand for scientific collaboration, with the lack of collaboration in a scientific network being a symptom of lower research productivity." In view of this, a picture and analysis of the co-authorship network of institutions in the GB literature is presented in the next section.

3.3.1. Institutions

Discovering the collaboration network of the institutions having high investment and interest in GGBR is useful in assisting research partnership and policy-making (Ding, 2011). VOSviewer was used to create this network. The type of analysis was "co-authorship", the unit of analysis was "organizations", and the counting method "fractional counting". As well, the "minimum number of documents of an organization" was set to four, while the "minimum number of citations of an organization" was set to 10. Of the 11323 organizations found, 24 met these thresholds and were included in the resultant network, which was visualized using Gephi, as illustrated in Fig. 5.

Fig. 5. Collaboration network of institutions in the GB literature.

The hyperlink-induced topic search (HITS) in Gephi, usually referred to as hubs and authorities, represents an algorithm whose work is to determine influential nodes (Khokhar, 2015). For every node in the network, the HITS algorithm produces two dissimilar scores, an authority score and a hub score. A higher hub score shows a more influential node in terms of serving as a key reference source. Authority score, however, provides insight into the quantity of useful information stored in a node (Hossein et al., 2018a). The higher the authority score, the more influential the node is in terms of serving as a useful information source (Cherven, 2015). More information on hub and authority scores can be found in Kleinberg (1999). The HITS algorithm was used to calculate the hub scores for the institutions in the network. These hub scores were then used to resize and recolor the network nodes, with larger nodes and lighter shades representing higher hub scores.

As shown in Fig. 5, institutions from China, Singapore, Australia, Hong Kong, and Ghana have been successful in establishing collaborative relations in conducting GB research. On the contrary, institutions from countries such as the US, the UK, and Canada demonstrate limited institutional cross-linkages. This might indicate the absence of cross-fertilization of GB research ideas at the institutional level. Collaborative relationships must be nurtured across the GGBR network if the highest standards of scholarship and debate are to be accomplished (Hosseini et al., 2018a).

3.3.2. Countries

Scientific collaboration network of countries helps in appreciating the countries that are active in the relevant research area (Chen, 2014). In order to identify these countries, the most influential ones, and the collaborations amongst them, a network was constructed using VOSviewer. The type of analysis was "co-authorship", the unit of analysis was "countries", and the counting method was "fractional counting". Furthermore, the "minimum number of documents of a country" and the "minimum number of citations of a country" were both set to 30. Of the 230 countries found, 40 met these thresholds and were included in the resultant network, which was visualized using Gephi, as illustrated in Fig. 6.

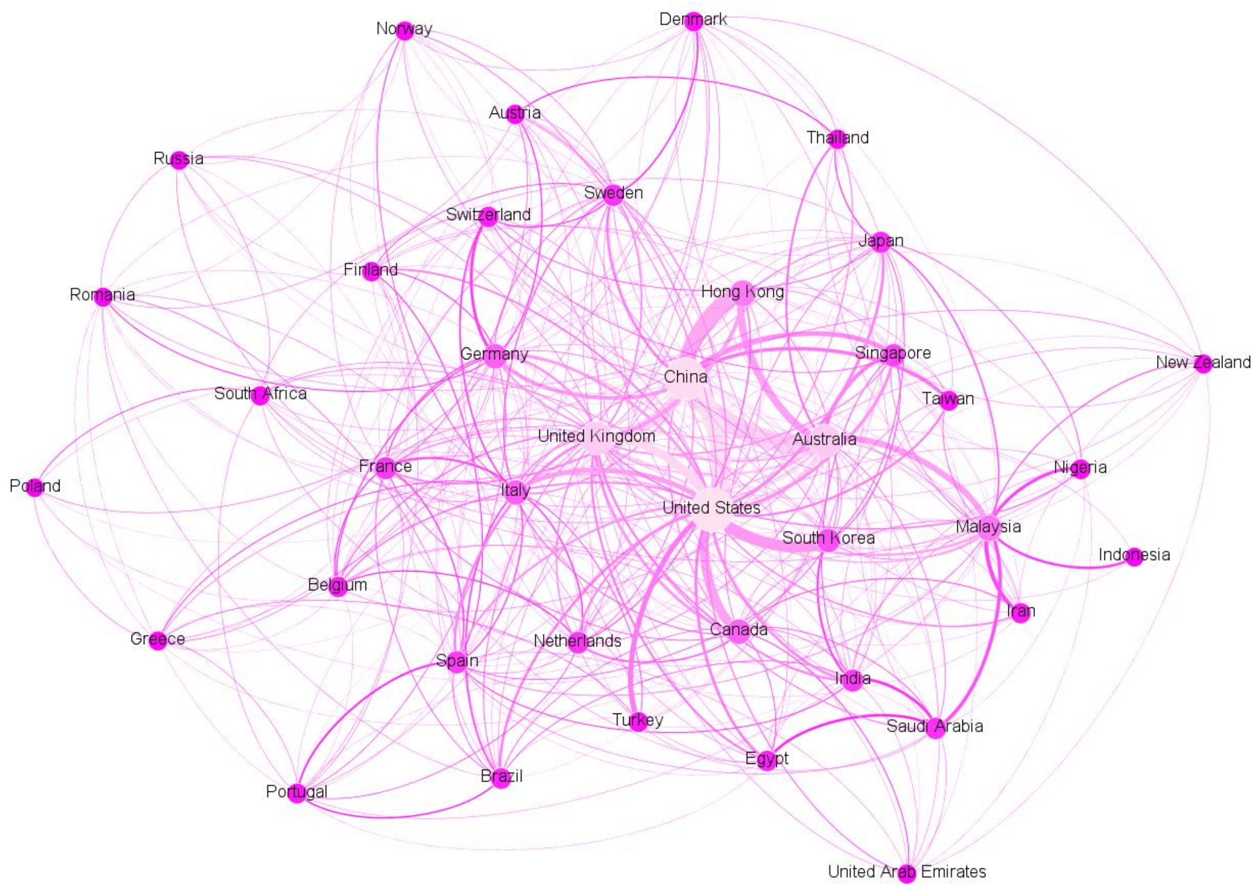

Fig. 6. Collaboration network of countries in the GB literature.

Weighted degree values were used to identify the most influential countries in the network. Nodes were recolored and resized based upon their weighted degree values, with larger nodes and lighter shades representing higher weighted degree values. The network reveals these key findings:

- Based upon the weighted degree values, Table 3 presents the top 15 countries in the network. The US and China were the top-ranked countries, implying that they are the biggest contributors to GGBR. Whereas the highest rank of the US coincides with Darko and Chan's (2016) finding, the results of the present study may be explained by the fact that "the US and China are the two largest carbon emitters in the world" (Chen et al., 2019, p. 604). Researchers and practitioners from these countries believe that promoting GB can aid to mitigate carbon emissions and hence achieve sustainability. The UK is the third most influential country in the collaboration network in GGBR; however, its links with the US and China are relatively not very strong. Accordingly, institutions in such influential countries must reform policies to nurture collaboration with each other, in order to further improve global collaboration and knowledge exchange within the GB research area.

Table 3

Top 15 countries collaborating in GGBR.

Countries	Weighted degree value	Rank
United States	296	1
China	267	2
United Kingdom	173	3
Australia	168	4
Hong Kong	95	5
Malaysia	93	6
Canada	79	7
Italy	77	8
Germany	76	9
South Korea	64	10
Singapore	55	11
Spain	51	12
India	50	13
France	48	14
Netherlands	45	15

- With regard to the strengths of links, the strongest links were amongst the paired countries US–China, China–Australia, and China–Hong Kong. However, compared to the total of 368 links in the network, very limited such strong links are formed. This may be as a result of the lack of cross-country comparative studies in the existing body of GB knowledge for validating findings and theories in diverse settings.
- Numerous countries in the network (e.g., United Arab Emirates, Portugal, Greece, Poland, New Zealand, Romania, Russia, Norway, Denmark, and Brazil) had weak collaboration links

to the main streams of GGBR (key nodes) and other network members. This should be considered by these countries in the refinement of their research policies, as they are placed far from the main collaboration network in GGBR.

- Developing countries were underrepresented in the network. Several barriers to the widespread adoption of GB in developing countries stem from a dearth of knowledge and awareness of GB (Nguyen et al., 2017). Therefore, this isolation from the core clusters of GB knowledge creation is very disadvantageous to the GB adoption trend within these countries.

4. Discussion and recommendations

Publication in the field of GB commenced in the 1970s, however, it is within the present century that publications in the double or triple numbers every year have constantly been seen. In fact, the number of publications has greatly increased in recent times, validating the sustained rising interest in GGBR. In the face of this increasing interest, the current global body of GB knowledge still has gaps and limitations, which become evident when the large corpus of literature is comprehensively and thoroughly analyzed (see Table 1). To date, the GGBR has directed special attention to certain themes while being seriously biased toward other themes. The environmental sustainability aspect of GB has been a central focus. On the contrary, the social and economic sustainability aspects are noticeably neglected; whereas studies about salient themes such as project management issues and processes, recycled, sustainable concrete, implementation and integration of advanced AI and GB technologies, and optimization are largely missing. This underlines the partial nature of the current GGBR. The GGBR should recognize that sustainability is a "triple bottom line" idea incorporating environmental, social, and economic dimensions and goals (Elkington, 1997). As such, focusing on only the environmental aspect is insufficient for realizing the full potential and benefits of GB.

Consequently, greater efforts are necessary to make the social and economic sustainability aspects of GB mainstream features of GGBR. In addition, Robichaud and Anantatmula (2011) also concur that the GB literature needs further studies that explore green project management, from the project management processes to the integrated team approaches implemented on GB projects. Although this issue was highlighted virtually a decade ago, it still has not been given the level of attention it deserves in the extant GGBR. GB projects inherently vary from their traditional counterparts. They necessitate the application of special building materials, practices, and technologies to accomplish sustainability. More in-depth discussions and explanations about the unique features that make GB projects significantly different from their traditional counterparts could be found in Robichaud and Anantatmula (2011). These unique features reflect the increased need for more studies specifically focused upon green project management issues and application of innovative AI technologies such as BIM in GB. In order to address the deficiencies in the current GGBR, the following suggestions should be considered and implemented:

- Scholars in the GB area must widen their focus beyond environmental sustainability to consider and include the whole sustainability framework. In this respect, the life cycle assessment (LCA) approach must be implemented for inclusive assessment of the social and economic impacts (in addition to the environmental impacts) of various categories of buildings and building materials in GB evaluation, at the building and project levels. At these levels, social aspects such as health and safety, occupants comfort, and accessibility for disabled people (Yuan and Zuo, 2013) must be incorporated into the LCA; whereas at the company and local community levels, corporate social responsibility performance, stakeholder engagement, living quality, job and professional development opportunities, sustainability education and awareness, etc. (Mateus and Bragança, 2011) must be incorporated. From the economic sustainability perspective, aspects such as life cycle costs (capital and operation costs), profitability, productivity, affordability, and economic value (Berardi, 2013) should be addressed.

- Project management issues have been widely studied in the broader construction research arena with increasing concentration on traditional construction projects. As the topic of sustainability has become commonplace within industry and academia, it is high time for researchers to shift their focus to creating clusters of research projects that focus on particular project management issues – e.g., project success, productivity, and optimization – in GB projects specifically. This initiative is proposed in view of the present study's findings, and Robichaud and Anantatmula's (2011) work could be a useful reference for such future studies. Hosseini et al. (2018a) indicated that such focused studies are beneficial for sparking focused scholarly debates and can help GB researchers move from preliminary stages of research to a mature state, namely, refinement and extension. Moreover, to enrich the previous efforts, future studies in this direction are advised to employ and integrate AI techniques for analyzing "big" data from actual GB projects, rather than analyzing perception-based data using ordinary statistical analysis methods. BIM, genetic algorithms (GAs), support vector machines (SVMs), neural networks (NNs), and fuzzy logic (FL), for example, represent AI techniques that can be used to tackle green project management matters, such as sustainable design optimization, integrated project delivery (IPD), productivity optimization, and project success measurement and prediction (Ko and Cheng, 2007; Wong and Fan, 2013; Lu et al., 2017). Another promising future research direction would be to explore the best way to integrate different AI technologies into various GB project life cycle stages.

- The WorldGBC (2018c) argued that every GB rating system is different, and that every country must develop GB rating systems that are best suited to its specific market. There is therefore an enormous opportunity for future research to target developing and diffusing quality GB rating systems for countries that have yet to develop their own rating systems. Whereas the WorldGBC supports this and as such has "launched the Quality Assurance Guide for Green Building Rating Tools to guide new, emerging, and established rating tools to ensure that their development and implementation is robust, transparent, and to a good standard" (WorldGBC, 2015), previous works in this line (Shad et al., 2017) did not follow this guide. To ensure quality, future research should follow this guide while focusing on developing GB rating systems for different building types and even whole neighborhoods within specific countries. In this line of research, the GB evaluation process also offers a fertile field for implementing AI technologies. Fusing BIM and ontology, for instance, can be effective for facilitating intelligent GB evaluation where human experts' shortage of limited experience and energy, as well as laborious, time-consuming, and error-prone issues related with manual GB evaluation are dealt with (Jiang et al., 2018). Future research could explore the potential of integrating many different AI and data mining techniques in GB evaluation.
- Further research should also be done in the areas of concrete, recycling, and green technologies. It is known that to be able to significantly deal with the impacts of construction and demolishing wastes on the environment, the rate of recycling must be above 90%, such as high target (Coelho and Brito, 2012). This calls for more research to further the manufacture and widespread use of construction materials such as recycled concrete. Utilization of green technologies is necessary to implement GB projects, and GBs in different settings are different because they are designed and built to the local climate and sustainability necessities

(Zuo and Zhao, 2014; Koebel et al., 2015). Accordingly, the technological innovations required for developing efficient GB projects within different settings are different; hence, the need for further studies exploring the effective green technologies to attain GB in different settings. Such studies can further look at developing frameworks and strategies for removing stumbling blocks and facilitating the wider application of green technologies.

The findings of this study indicate that there is lack of collaboration among actors – institutions and countries – involved in GGBR. The links among many of these actors were absent or frail. Despite having certain downsides, research collaboration offers great benefits, as discussed by Scherer (2005). Therefore, this problem in the existing GGBR should be addressed considering the following recommendations:

- Research institutions and funding agencies interested in GGBR ought to formulate policies for encouraging global, interinstitutional, and interdisciplinary research collaboration as a necessity for applying for related funding schemes.
- There must be a change in the way the performance of academic and research staff, institutions, and funding agencies are evaluated. This change should encourage more collaborative research efforts and projects.

5. Conclusions

This paper presented the outcomes of an inclusive science mapping analysis of the global body of literature on GB from its advent in 1974 to the present (2018). It provided a crystal-clear picture of the structure of the body of GB knowledge and detected the gaps in it. This study identified 38 main areas of GGBR, in and amongst which several fundamental problems were discovered. Based on these problems, recommendations that could be instructive in providing practical directions on how to address the drawbacks inside the existing literature were offered.

This research also benefits the field by identifying the extant research networks. With the help of these networks, those active and interested in GGBR can achieve an understanding of the topical issues, institutions and countries involved, how all these are linked, as well as the outlets that disseminate the research ideas and discoveries. Thus, this study can aid researchers and practitioners synthesize various kinds of information to capture the state-of-the-art of GGBR. Additionally, the knowledge gaps identified, and the future research directions offered may serve as a motivation for researchers and practitioners to work on the next generation of research to assist the development of GB around the world. Where possible, future studies must focus on technical and engineering solutions in GB, instead of generic issues. Today, the industry and prominent outlets seem to be more interested in technical studies, as generic studies seem to have hit saturation point (Hosseini et al., 2018a; b).

In spite of its contributions, this study has limitations. The analysis was based upon the dataset extracted from Scopus, therefore may be affected by any intrinsic limitations of Scopus's coverage of publications. As well, the literature was searched using certain keywords. Moreover, this study was limited to only journal articles. For these reasons, the research findings might not fully reflect the whole available literature on GB. Also, this study was mainly guided by social network analysis principles concerning citation networks. Utilizing citations as the main indicator of quality, impact, and connections of academic works may be open to criticisms. The limitations of this study should be considered when interpreting the findings. Future research may however attempt to address the limitations via utilizing data from various sources, and a variety of indicators for assessing impact, quality, and connections in the literature. It might also include all literature types.

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