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Scientometric Review of Global Research Trends on Green Buildings in Construction Journals from 1992 to 2018

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Abstract

Following the 1960s environmental movement and the energy crisis in the 70s, evidence spurred research on renewable energy and energy efficiency practices. As a result, the green building (GB) movement emerged in the 90s to promote buildings which are designed to reduce the consumption of energy, electricity, water, materials, natural resources as well as improve environmental performance and human health over the whole lifecycle. With a prime goal of improving energy efficiency, GB has gained recognition in national and international energy policies. Following manifold exemplary projects and reported benefits, GBs research has recorded a tremendous increase over the years. Thus, it is essential to monitor the research progress to identify areas that require further research. This paper recruited the bibliometric data of 1147 GBs research articles and conducted a scientometric review. The review showed that GBs research publications increased steadily from 1992 to 2018. This highlights the increasing commitment towards the initiative. The paper found that at least 44% of all countries in the world are involved in GBs research. Ten (10) broad GB research areas in existing studies identified and discussed and areas for further research were proposed. Thus, the paper offers a useful reference point to early-stage researchers, funding authorities, energy policymakers and industry professionals on the research progress in GBs.

Keywords: green building; sustainable construction; network; scientometric review

Word count: 10,864

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1. Introduction

The concept of green building (GB) dates to the nineteenth century or even earlier. As of 1851, passive systems comprising 'roof ventilators and underground air-cooling chambers' were used to improve the indoor air quality of the London's Crystal Palace [1]. GB *also known as sustainable or high-performance buildings* have been intertwined within the manifold milestones of global sustainability ranging from the 1972 UN conference on the Human Environment in Stockholm; the 1973 OPEC oil embargo; the 1987 Brundtland Report of the UN World Commission on Environment and Development; development of the UK's 1990 Building Research Establishment Environmental Assessment Method through to the 1998 Green Building Challenge in Vancouver of British Columbia and the establishment of the World Green Building Council in San Francisco in 1999 [1]. The contemporary green building reinvigoration is driven by the compelling need to adopt building practices that are energy efficient and eco-friendly. The combined impact of the 1960s environmental movement and the 1970s energy crisis spurred research on renewable energy sources and energy efficiency [1,2].

The 1990s marked the period of formalization of the GB field. Robichaud and Anantatmula [3] noted the 1990 green building movement witnessed the emergence of terms such as "sustainable building", "whole building design", "sustainable design", "integrated design", "high-performance building" and "green building" in the architecture, construction and engineering industry. The Office of the Federal Environmental Executive [4] defined GBs as buildings designed to reduce the consumption of energy, water, materials and natural resources towards minimizing environmental impacts and improvement of human health. GB construction is currently being implemented across different countries as a way of reducing the energy consumption of the building, minimizing resources depletion, reducing water footprint and contributing to sustainable development goals. The approach minimizes the carbon footprint and environmental threats posed by the built environment. Due to the benefits and opportunities offered, GB research has witnessed increasing commitment in both the industry and academia, in a global context [5,6]. The rising trends of GB research have been attributed to the significant positive impact of the approach to climate change mitigation, construction waste reduction, human health improvement [7] as well as conceited governmental commitment through GB standards, codes and policies [8–13]. It has also been demonstrated that GBs improve ecological habitats, energy performance, resource conservation, biodiversity protection, and epitomized by lower life-cycle cost [14–16]. Studies have shown that GBs come along with economic benefits such as 25% productivity improvement and 30% decreased energy consumption [1,17]. These findings demonstrate and highlight the higher opportunities offered by GB. Axelsson *et al.* [18] noted that the paradigm shift towards GB is driven by the global collective prioritization of the sustainable development goals. Obviously, these benefits, characterized by GB have both intra-and intergenerational perspectives. It is therefore not surprising that the GB concept is receiving international recognition and prioritization in the built environment.

However, disparate perspectives and research priorities have emerged in the GB research discourse [19,20] due to differences in socio-political structures and fragmented nature of construction industries around the globe. Thus, it is nearly impossible to have unified green building policies, priorities, and blueprints from a global perspective [6,21]. Previous researchers noted increasing growth in GB research publications from both developed and third world countries [3,6]. The marked rise in a number of research publications on GB could reflect the research commitment towards informing evidence-based policy formulation. This has implications for industrial innovation. Cohen et al. [22] stressed that industrial development is greatly influenced by evidence from academic and public research. The construction industry in one country could rely on published evidence from other countries to design policies, where bespoke research is not feasible. While the research increase will most likely drive and promote GB development, the larger census of published GB literature engenders challenges to different consumers of GB research output. To early stage researchers, larger volumes of research publications need to be reviewed to identify research gaps for further investigation. Particularly, the increasing volume of published works complicates the process of findings grey areas for efficient and intensive research [6]. It renders essential knowledge retrieval difficult and might thwart the assimilation of research evidence by industrial professionals.

Recognizing the waves of GB research, some researchers reviewed trends on GB research. Prominent among them are Zuo and Zhao [21], Darko and Chan [6] and Huo and Yu [23]. The review of Zuo and Zhao [21] found that prior to their study, GB research had focused on "quantification of cost and benefits of green building", "measures to achieve green building", and "coverage and definition of green building". Two years later, Darko and Chan [6] reviewed 105 articles in 10 construction journals and concluded that previous studies focused on "green building project delivery and developments", "green building certifications", "energy performance", and "advanced technologies". Indeed, such constituted an extension of findings reported in Zuo and Zhao [21]. In 2017, Huo and Yu [23] conducted a manual scoping review of 226 GB studies in 10 construction journals and also concluded that existing studies focused on "green building management", "benefits and barriers to green building development", "green building performance", "stakeholder behavior analysis" and "green building strategies". Although the sample sizes of the latter two studies are sufficient for manual reviews, further evidence could be revealed by examining wider coverage of articles and journals. The marked difference in samples (121) between the latter two reviews within a period one year highlights the rapid growth of GB research publications.

Besides, there are increasing concerns about the unsatisfactory state of research collaboration between and among researchers, institutions, and regions in some aspects of the sustainable construction frontiers [20]. Albeit relevant, this concern cannot be verified through manual reviews. This collaboration is also essential as it facilitates deeper exchange and transfer of ideas within the GB research discourse. Also, the manual qualitative reviews of Zuo and Zhao [21], Darko and Chan [6] and Huo and Yu [23] did not map out the networks of GB researchers, countries and territories. Thus, these previous reviews did not examine the extant literature to such depth to include aspects such as co-citation networks, co-occurrence network, bibliographic coupling. Amid these generic reviews, manifold scoping reviews have also emerged in the GB research domain. For instance, review on barriers to green building adoption [24], drivers [25], green building materials [26–28], green rating systems [29–32], environmental performance [33], environmental assessment techniques [34,35], post-occupancy evaluation [36], life cycle evaluation [37], life cycle assessment models [31], external stakeholders [38], decision support tools [39], green building incentives [40], cost-benefit analysis [41] and evaluation standards [42] have been conducted. While these manual reviews have advanced our understanding of the research trends in the GB domain, they shared the limitations of lacking wider coverage; largely driven by the subjective judgment of the reviewers [43]; and cannot analyze the network of researchers, regions, keywords, and articles [19].

However, a scientometric analysis is capable of coping with the large universe of GB research publications and can also address the inherent limitations of the previous reviews. Recently, Olawumi and Chan [20] recruited 2094 bibliometric record in their scientometric review of research trends on sustainability and sustainable development from 1991 to 2018. However, Olawumi and Chan's review focused on sustainability in general and did not identify GB as a major sustainability research area. In their keyword analysis, 'sustainable building' scored the lowest citation burst (3.81) among fourteen (14) prominent keywords in sustainability research studies. Meanwhile, the bibliometric data of GB studies in the current paper constituted 55.8% of the sample size considered in Olawumi and Chan [20]. Generally, Olawumi and Chan [20] barely discussed green building issues in their scientometric review and also included fewer construction journals.

To extend the previous manual reviews and address their inherent weaknesses, this paper conducted a scientometric review of GB research publications in construction journals. A network of researchers' collaborations, document co-citations, keyword co-occurrences, and geospatial distribution of most active GB research countries are critically examined. In this regard, the review pursued the following research objectives: (I) to critically examine the highest impact journals in GB research; (II) to identify the most productive GB researchers and territories; (III) to generate a geospatial network of the active GB research countries; (IV) to identify the highest impact research keywords and co-occurrence networks; and (V) to deduce the salient and emerging research themes from the keyword analysis. Thus, it is expected that this objective assessment will reveal the broader themes of research studies conducted in GB and will highlight areas that require further research as well as opportunities for collaboration among researchers and research institution. The holistic evaluation will generate distilling evidence to both academics and industry practitioners on the state-of-the-art research on GB. By combining a scientometric analysis with qualitative discussion, a more holistic science mapping is achieved. The findings may be relevant to multitudinous groups of GB research stakeholders. Particularly, researchers will easily identify the prolific GB research citizens in the international community and will also assist them to choose research outlets that will receive wider consumers.

2. Research Methods

This section outlines the research methods and tools used in conducting the scientometric analysis. Subsections are provided to offer a comprehensive outlook of the research methodology adopted. In Fig. 1, a flowchart of the research methodology is presented. The subsequent sections provide a brief description of the major components of the flow chart.

2.1 Science Mapping and Scientometric Analysis

In this paper, a quantitative-based science mapping technique is deployed. Thus, it was instructive to adopt a technique capable of quantitatively mapping out patterns and networks in a larger set of bibliometric data [44]. Indeed, science mapping (visualizing bibliometric network) has become a suitable tool used by researchers for describing and diagnosing large collections of bibliometric data for several purposes [45]. The approach addresses the challenges associated with manual reviews when trying to map the working linkages of researchers, keywords, countries and research outlets within a research domain [46]. Although science mapping is broadly classified into three major techniques comprising informatics, bibliometric and scientometric analysis [20], the latter approach satisfies the objectives and tenet of the current study. Indeed, these techniques are overlapping but can also be applied independently. Whiles bibliometric analysis seeks to scientifically map the literature per se, scientometric analysis extends the bibliometric analysis to encompass the measurement and analysis of the network of researchers, institutions, and countries within the literature [47]. As noted by Hosseini *et al.* [20], a scientometric analysis deploys bibliometric data, techniques, and methods to scientifically map the literature.

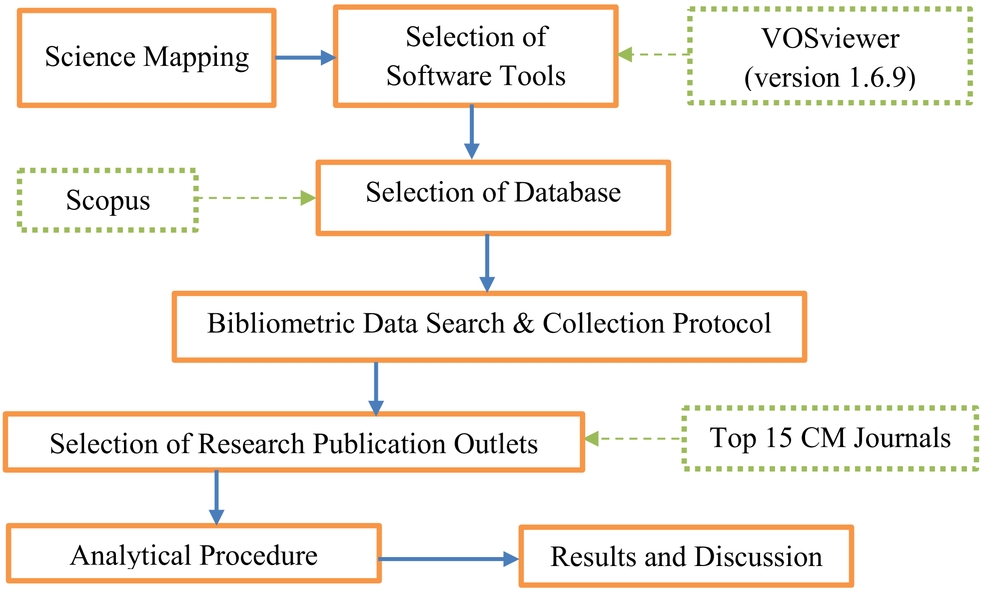

Fig. 1: A Flow Chart of Research Methodology

2.2 Selection of Software Tools

Several software tools have been developed to scientifically map literature with wider coverage [44]. Whiles some of these tools are developed for general science mapping, some have specialized application within the science mapping philosophy. Again, these software tools have disparate strength, capacities, and limitations. With the intent to map and visualize the nature of extensive scholarly datasets, the choice of the software tool is essential. The adoption of a tool (s) will require awareness of their relevance to the study, features, and limitations [48]. Whiles CitNetExplorer, CiteSpace, Gephi, BibExcel, VantagePoint and VOSviewer exist as common and popular software tools for science mapping, VOSviewer (version 1.6.9) was selected to scientifically map the extant literature in the GB research. VOSviewer is an open source software tool. The tool offers sufficient features for visualizing bibliometric network and for scientifically mapping the literature. The text-mining tool is uniquely designed for visualizing and analyzing bibliometric networks [49]. The tool has been deployed by previous researchers for Scientometric reviews. For instance, in the construction management research domain, VOSviewer has been used to map knowledge in offsite construction [20,50], building control [51], building information modeling [52] and public-private partnership [53]. Thus, VOSviewer was considered sufficient enough to achieve the objectives of the study.

2.3 Selection of Database

Scopus and Web of Science are the two common databases that index construction management research publications [54]. Whiles the two offers comprehensive platforms for extracting bibliometric data, the number of publications indexed in these two databases on the same research area tend to differ. In this study, Scopus was selected because it had wider coverage of the research publications and included more recent bibliometric data compared to Web of Science and Google Scholar [55]. Again, previous reviews in construction management and engineering research have deployed bibliometric data from Scopus [20,50,52,53]. Particularly, VOSviewer offer network analyst the opportunity to import bibliometric data from Web of Science, Scopus, Dimensions, PubMed, RIS, Crossref JSON, and Crossref API. Thus, the choice of Scopus was consistent with the acceptable file formats of VOSviewer (version 1.6.9).

2.4 Bibliometric Data Extraction & Journals Selection

To extract a wider and more reliable set of the bibliometric data, the most used interchangeable keywords for GBs were deployed to extract the datasets. Zuo and Zhao [21] identified some interchangeable terms used to describe GB in the construction management (CM) genre. However, for the purposes of this study, the precedent established by Darko and Chan (2016) was considered sufficient for the current study. Thus, "Green Building" OR "Sustainable Building" OR "Construction Sustainability" OR "Green technology" OR "Green Technologies" OR "Sustainable Construction" were used as the keywords to retrieve the bibliometric data on GB research. Searching these keywords using the "title/abstract/keyword" functionality of the Scopus database, without defining the time limit, generated 13,276 of articles (as of September 2018), including studies outside the construction management domain. Thus, the search combination functions for refining data retrieval was deployed. The "document type" was set to "article or review". The objective was to retrieve only original and review articles in green building. The rest (e.g. conference papers, etc.) were not included because it has been noted that they complicate the analytical process and yet, add very little to the results [20,56].

The "source title" was used to refine and limit the journals to be considered. In this section, the top journals in construction management were considered. This is due to the consensus that articles published in these journals are regarded as the landmark research studies [57] and are most suitable for a science mapping application. Besides, previous Scientometric analysis scientifically mapped the research publications within these high impact journals [58]. Also, Santos *et al*. [57] noted that the top-ranked research outlet constitutes the catchment to scientifically map published literature. In all, the following journals were considered: *Construction Management and Economics; Journal of Green Building; Journal of Construction Engineering and Management; Building and Environment; Journal of Management in Engineering; Sustainable Development; Habitat International; Building Research and Information; and Proceedings of the Institution of Civil Engineers-Civil Engineering; Journal of Cleaner Production; Energy and Building; Construction Innovation; Automation in Construction; and Journal of Civil Engineering and Management.*

Also, based on the precedent of Darko and Chan [6], the "subject area" was restricted to "construction industry; building construction; construction management; construction engineering and management". Again, the "source type" was limited to "journals" and the "language" section restricted to "English". A total of 1147 (as of September 2018) research articles met all the restrictions. The bibliometric data was downloaded in two forms: "Comma-

Separated Values (CSV)" file and "Research Information Systems, RIS" file. However, the CSV file was imported to VOSviewer to scientifically map the GB research literature.

2.5 Analytical Procedure

After importing the bibliometric data into the software tool (VOSviewer), the analysis was conducted in different stages, followed by cross-checking to ensure consistency and reliability. Firstly, the VOSviewer functionality "Create a map based on bibliometric data" was used to create networks of journal citations, keyword co-occurrence, bibliographic coupling, co-authorship, document citation, and country citations. Therefrom, the total citations, average citations, normalized citations, average normalized citations, links, and total link strengths of authors, articles, and countries were recorded. Maps were created to illustrate the networks and accompanying tables were created to quantitatively summarize the numerical metrics of the networks. Secondly, the VOSviewer functionality "Create a map based on text data" was deployed to generate the map of terms co-occurrence based on the text data. This step was used to create a map of the main GB research areas. The keywords were analyzed and grouped into main research areas and the associated most representative keywords. These are shown in Fig. 11. Finally, the outputs were refined and reported in the results and discussion section of the papers.

3. Science Mapping Results and Discussions

3.1 Annual Publication Trend

Although the concept of GB has been advanced for several decades, it appears GB research publications in construction journals dates to the last two decades. The study recruited a total of 1147 published GB articles between 1992 and 2018. The bibliometric data retrieval query was not time-unconstrained but the earliest publication (s) in the construction journals appeared to be in 1992 (Fig. 2). Similarly, in the review of Darko and Chan [6], the reference year was found to be 1998, although their search spanned between 1989 and 2016. Indeed, the reference year of 1992 reported in the current paper could be due to the higher number of journals included relative to the review of Darko and Chan [6]. The publications consisted of 1082 original research articles and 65 reviews. Growing interest and increasing commitment to a research domain are expected to reflect in the annual publication trends in the field. Fig. 2 shows the annual GB research publications recorded between 1992 and 2018. Fig. 2 demonstrates that GB research has witnessed a steady growth over the 26-year period. Similar trends have been noted by previous researchers [6]. Relative to the performance of previous years, some years witnessed declined trends in the annual number of research publications. These can be observed in 2001-2005, 2009-2011 and 2014 (Fig. 2). Until 1998, the number of publications on GB was uniformly distributed annually, mostly in the neighborhood of 3 publications. This is justifiable because, during these years, the GB concept was still at the very early stage [14,59].

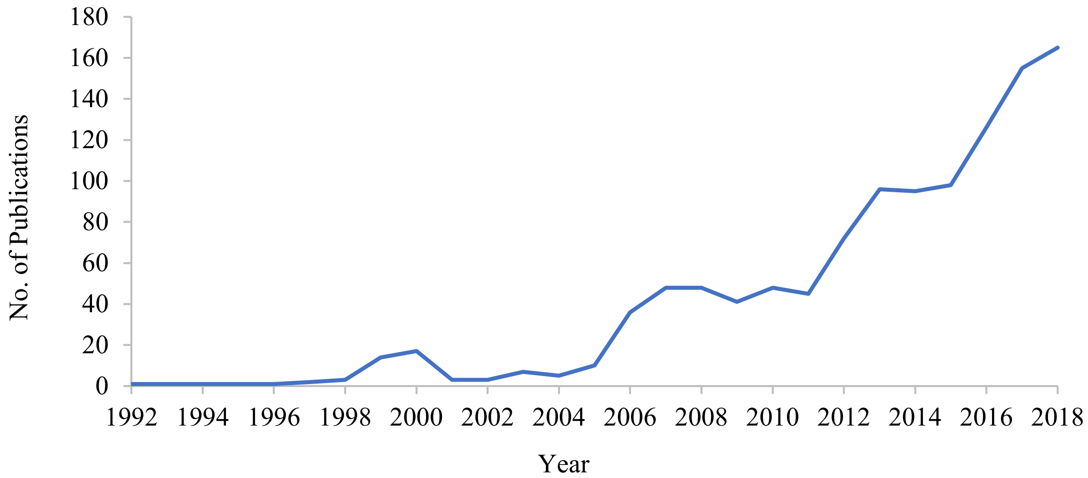

Fig. 2: Annual Publication Trend from 1992 to 2018

In the year 2000, a relatively significant number (17) was recorded for the first time and the trend declined swiftly and recovered continuously in 2005. Although an increasing pattern is observed, the trend assumed a sinusoidal pattern from 1998 to 2011. Nevertheless, the curve suggests that GB research is gaining much more interest and commitment. The steady growth between 2011 and 2018 could have been driven by the increasing concern about climate change, governmental interventions and the renewed commitment to establishing a sustainable built environment [3,6].

3.2 Science mapping of Research Outlets

Research outlets constitute one of the main platforms for disseminating academic developments and innovation. These outlets publish articles within defined scopes and boundaries. Identifying the key journals in GB research is a good starting point to systematically map the research trends in the field. In Fig. 3, journal citations network of 14 top construction journals that publishes GB research articles are shown. These research outlets had published at least five (5) GB research articles and achieved at least 20 citations. These were specified in the process of generating the network. Although this threshold is different from previous scientometric analyses [20,50,60], the combination was regarded sufficient because the previous reviews used an even lower combination of restrictions. Besides, there are no standards guiding the selection of documents and citations quantities. A detailed quantitative summary of the network is shown in table 1.

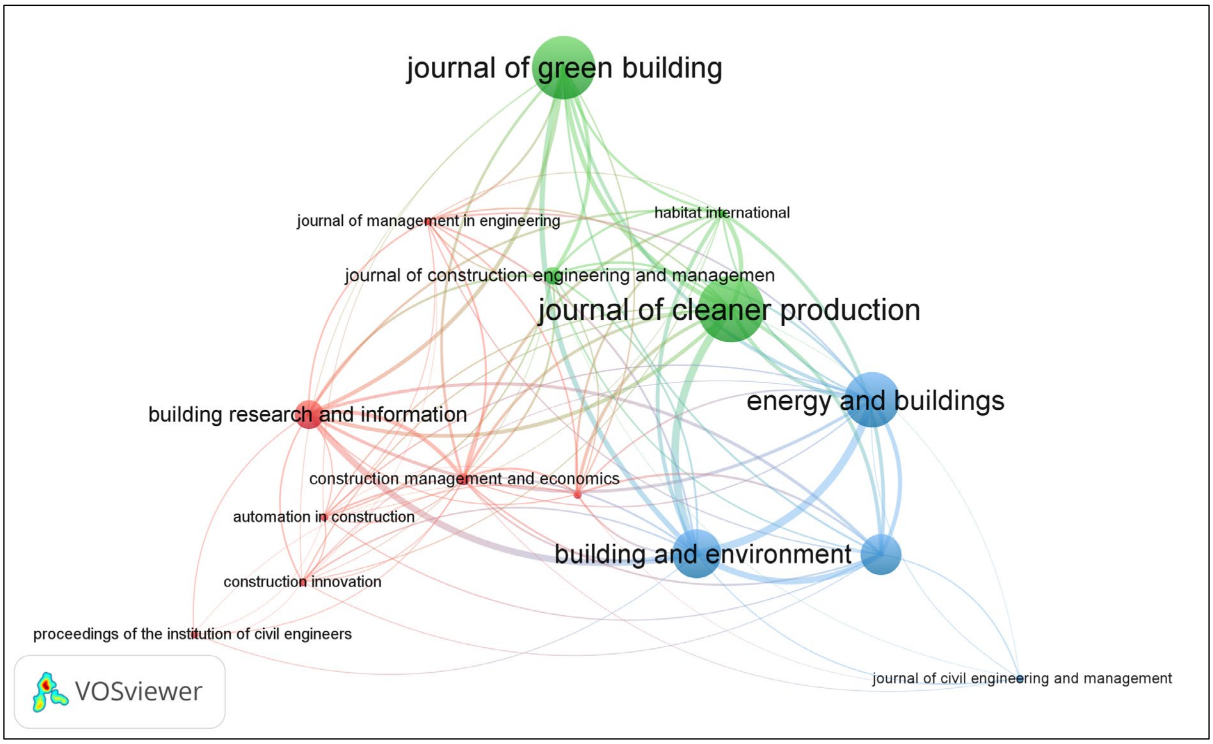

Fig 3: Network of Landmark Research Outlets in GB research

The map was generated using the source citation network function of VOSviewer and since the tool deploys distance-based maps, the size of the node (journal) reflects the impact (in terms of citation or number of articles) of the journal. For instance, *building and environment; energy and buildings; building research and information; and journal of cleaner productions* have relatively larger nodes than the rest of the research outlets. Closely located research outlets belong to a similar cluster and the connection lines (edges) demonstrates the contemporaneous citation linkages of the research outlets. For instance, *journal of green building* shows stronger citation link with *habitat international, journal of cleaner production and journal of construction engineering and management* within the GB research (Fig. 3). These journals mostly get co-cited in GB research articles.

Table 1: Prominent research Outlets in Green Building Research

Research Outlet	No. of Articles	Total Citations	Av. Citations	Links	Total Link Strength	Av. Norm. Citations
Building and Environment	146	4857	33	14	485	1.45
Energy and Buildings	164	4550	28	13	279	1.23
Building Research and Information	87	3069	35	13	275	1.06
Journal of Cleaner Production	198	2732	14	13	358	1.48
Construction Management and Economics	36	1050	29	14	164	0.80
Journal of Construction Engineering and Management	54	951	18	13	141	0.83
Journal of Green Building	188	847	5	12	255	0.19

Automation in Construction	25	696	28	13	61	1.53
Habitat International	23	655	28	12	197	1.68
Sustainable Development	15	596	40	14	115	1.66
Journal of Management in Engineering	21	483	23	12	91	1.25
Sustainability (Switzerland)	122	455	4	13	244	0.58
Construction Innovation	25	278	11	13	50	0.52
Journal of Civil Engineering and Management	12	180	15	7	16	0.71
Proceedings of the institution of civil engineers: Engineering sustainability	23	154	7	6	13	0.43

Generally, each journal has connections (citations) with the 14 other journals, suggesting that most research articles make references to other GB research articles published in all these journals. For instance, reviews such as Zuo and Zhao [21], Darko and Chan [6], Huo and Yu [23], Jin *et al.* [50], Hosseini *et al.* [20] and the current study cite all these journals in a single study. Also, the research outlets have been grouped into clusters using colors. Each cluster is either related by the scope of GB research areas or frequency of co-citation in the GB discourse. Within the clusters, closely positioned journals have stronger citations links than those isolated within the cluster. For instance, within the purples cluster *building information and research; construction management and economics; automation in construction; and construction innovation* have stronger citation (or publication) connections within the cluster relative to the *proceeding of the institution of civil engineers*. Also, within the cluster of *building and environment; energy and buildings; and sustainability, the journal of civil engineering and management* have weaker citation connection with the rest of the outlets in the cluster.

In table 1, there is a strong positive correlation between a total number of articles, total citations, and total link strength, suggesting that each of these indices can be effectively deployed to comparatively measure the productivity and contribution of these research outlets. Computing the Pearson product moment correlation coefficient (r) between average citations and the rest of the indices showed that there is an insignificant weak negative correlation between average citations and the total number of research articles (r=-0.22). There is also an insignificant weak positive correlation between average citations and total citations (r=0.43, p=0.10); as well as between average citations and total link strength (r=0.21, p=0.44). However, there is a significant strong positive correlation between average citations and average normalized citation (r=0.77, p=0.00). Effectively, the average annual impact of a journal is related to the average number of publications.

Based on a number of articles, the top 3 most contributing journals include *journal cleaner production (198), journal of green building (188) and Energy and Buildings (146)* whereas *the journal of Civil Engineering and Management (12)* contributed the least number of publications. However, the order changes significantly in terms of citations. The top five (5) most cited research outlets in the GB research include *building and environment (4857), energy and building (4550), building research and information (3069), journal of cleaner production (2732) and construction management and economics (1050)*. The least under this metric is the *proceedings of the* *institution of civil engineers: engineering sustainability (154)*. On annual bases (evidence from average normalized citations), the 5 most influential journals include *habitat international (1.68)*, *sustainable development (1.66), automation in construction (1.53)*, *journal of cleaner production (1.48)* and *building and environment (1.45)*. Knowledge of these several measures of impact will guide researchers on the choice of journals to submit research articles.

3.3 Co-occurrence Network of keywords

Keywords are essential for indexation of research articles in databases and mostly reflect the theme of research publications. Thus, mapping all keywords within a set of publications could provide a holistic mental map of the knowledge domain or the main research areas of researchers in the given field. In Fig. 4, a co-occurrence network of author keywords used in 1147 GB research articles are shown. To accomplish this, best practices proposed by van Eck and Waltman [49], Oraee *et al.* [60], Jin *et al.* [50], and Hosseini *et al.* [20] were adopted. The "type of analysis" was set to "co-occurrence", the "counting method" set to "Fraction counting" and the "Unit of Analysis" was restricted to "Author keywords". By default, the minimum number of occurrences of a keyword was set to 5. Therefrom, 133 keywords out of 3262 keywords met the threshold. From this, a co-occurrence network of the keywords (Fig. 4), as well as number of occurrences and total link strength (table 2), were generated.

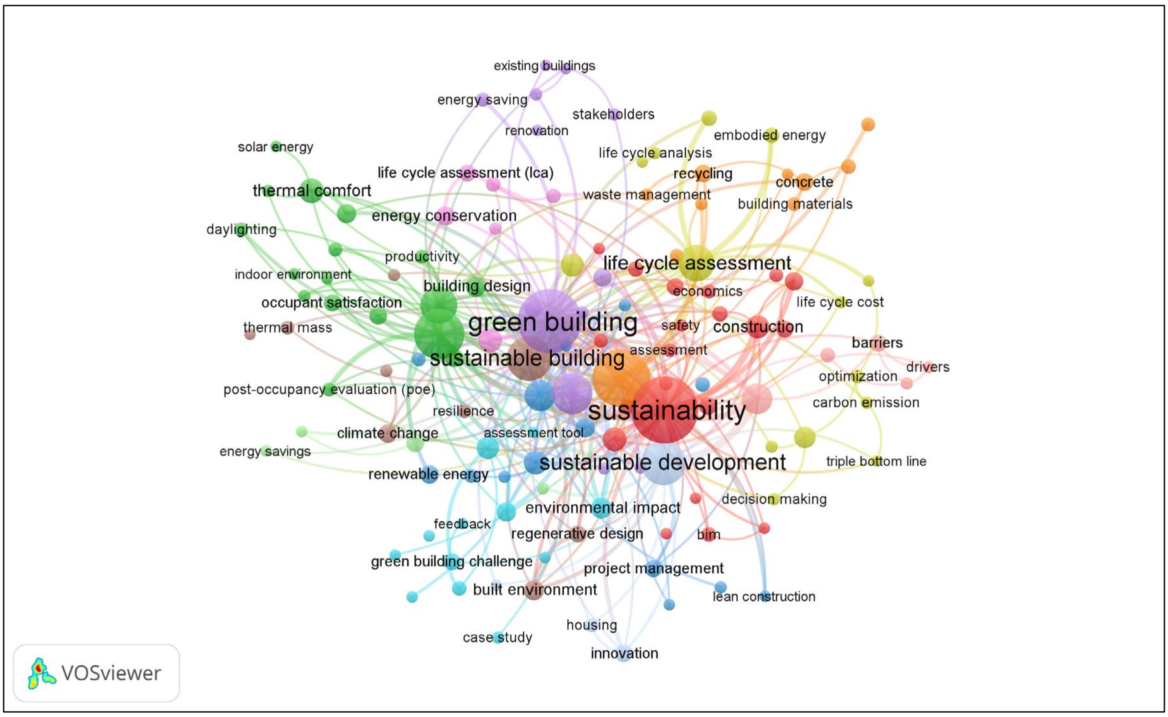

Fig. 4: Co-occurrence Network of Keywords

Based on a number of occurrences and total link strength, the top 25 frequently used keywords are shown in table 2. The size of a keyword reflects the number of times it appeared as an author keyword in the 1147 research articles. Also, closely located keywords indicate their co-occurrence in research articles. For instance, the keywords *sustainability, green building (s), sustainable construction, sustainable development, sustainable building, and LEED* have distinctly larger nodes than the rest of the keywords. Also, different clusters of keywords were grouped by colors (Fig. 4). Each cluster denotes keywords that are most frequently co-occur. For instance, keywords such as *thermal comfort, natural ventilation, indoor air quality, green building, daylighting and post-*

occupancy evaluation frequently co-occurred. These are represented by the green color and it is impressive because all such keywords are measures of indoor environmental performance in post-occupancy evaluations.

Table 2: Most Active Keywords in Green Building Research

Keyword	Occurrences	Total Link Strength
sustainability	149	119
green building	137	114
sustainable construction	113	68
green buildings	85	67
sustainable development	68	61
sustainable building	67	52
LEED	57	49
energy efficiency	46	42
life cycle assessment	45	42
construction industry	33	31
sustainable buildings	33	26
thermal comfort	21	15
buildings	20	18
energy	20	19
sustainable design	20	16
construction	19	18
energy consumption	19	17
environmental assessment	18	17
green technology	16	6
environmental impact	15	13
building design	14	14
built environment	14	14
BREEAM	13	13
energy conservation	13	10
natural ventilation	13	11

Computing the Pearson product moment correlation coefficient (r) between a number of occurrences and total link strength shows that there is a very strong and significant positive correlation ($r=0.989$, $p=0.00$) between the two indices. Thus, the higher the frequency of occurrences of a keyword, the higher the chances it will co-occur with other frequently used terms in the GB research discourse. Complimenting Fig. 4, table 2 provides the numerical statistics of the variations in the node sizes and total link strength (co-occurrence connection or links) of the keywords. Out of 3262 author keywords, these terms (table 2) constitute the top 25 high impact author keywords which co-occurred with other related terms at least 13 times from 1992 to 2018. The awareness of this should guide researchers on the appropriate keywords to use in their articles to facilitate wider indexing and retrieval of articles. This section involved the analysis of author keywords in the research articles, but a holistic analysis of all keywords is presented in section 4.3 to identify the main research areas in GB. This approach has been deployed in previous studies such as Song *et al.* [53], Zhao [62] and Jin *et al.*[50].

3.4 Co-authorship Network Analysis

The collaboration between or among researchers and institutions facilitate knowledge exchange, ideas sharing and innovations. These collaborations are also effective in joint funding applications [63]. Thus, this section presents a network analysis of the multi-authored articles to identify the key collaboration in the GB research. The minimum number of research articles and citations were set to 5 and 65, respectively. Only 25 authors and 15 documents met the threshold. These 25 authors were among 2676 authors in 1147 research articles. Since there was a restriction on the number of articles and citations, Fig. 5 effectively display the collaborations of the most contributing and influential researchers in the GB discourse. Their citations, normalized citations, and total link strength are shown in table 3.

Five clusters of productive and collaborative researchers emerged (Fig. 6). Researchers such as Chen X., Li B., and Li Y. tend to collaborate more often [64]. Also, Chan E.H.W., Xu P., Wu Z., and Zhang X. belong to one cluster of collaborative researchers, especially Chan E.H.W. and Xu P. [65–68]. Their collaboration is regional, within the territory of Hong Kong, between Chongqing University and the Hong Kong Polytechnic University. Again, Shen L., and Tam V.W.Y. constitute one cluster of collaborative researchers; Wang J. and Li J. constitute another cluster and Ye K., Zuo J. and Chen Q. also constitute a separate cluster of collaborative researchers. These collaborations were mostly intra-institutional (within or among departments) and inter-institutional. Some of the collaborations could be cross-departmental, institutional, and international. The clusters could reflect similar research interests and/or the collaborations.

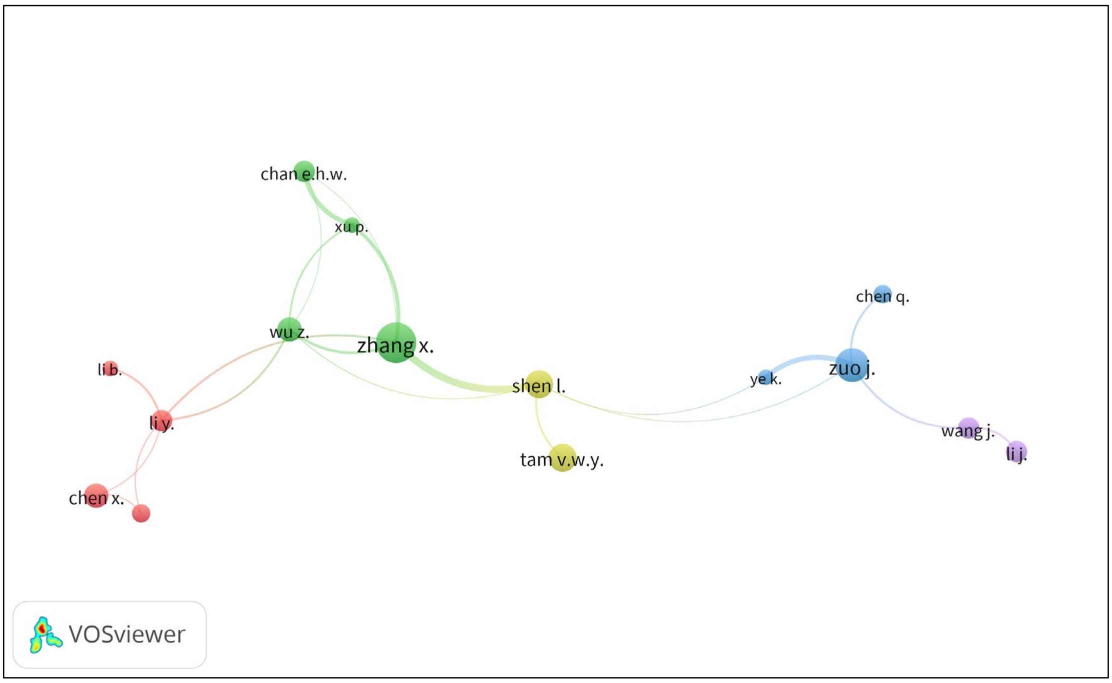

Fig. 5: Map of Co-Authorship Network

Within the clusters, a quantitative summary of the numerical indices of the co-authorship network is presented in table 3. In this context, the normalized citation is simply a measure of the total number of citations recorded by an author in an average year. Thus, the normalization of the citations standardizes the tendency of older articles having the opportunity of being cited higher than recent ones [49]. Although some of the collaborative authors are not visible in the network (Fig. 5) due to the edges restriction, authors who met the thresholds are shown in table 3. For instance, Darko A., Chan A.P.C., Cole R. J., Gou Z., Pearce A.R., Wallbaum H., Ahn Y.H., Chen P.-H., Hwang B.-G, Riley D., and Liu Y. did not appear within the network, albeit they met the thresholds. A cross-analysis of the research interest of the researchers showed that Gou Z., Pearce A.R., and Chen Q. share a similar interest in GB policies but their collaboration is not reflected in Fig. 5. This may be due to documents and citations restriction. In table 3, further analysis can be made. Out of 13 articles published by Darko, 11(Total link strength) have been collaborative within their cluster. Again, Zhang X. collaborated in 8 out of the 13 published articles within their cluster.

Table 3: Most Collaborative Researchers Analysis

Author	No. of Articles	Citations	Av. Citations	Av. Norm. Citations	Total Link Strength
Darko A.	13	146	11	2.91	12
Zhang X.	13	374	29	2.10	8
Chan A.P.C.	11	144	13	3.25	11
Cole R.J.	11	545	50	1.46	0
Gou Z.	11	137	12	1.08	2
Zuo J.	11	118	11	0.83	5
Pearce A.R.	10	142	14	0.39	5
Shen L.	9	448	50	1.97	6
Tam V.W.Y.	9	199	22	1.35	1
Chen X.	8	65	8	1.16	1
Wallbaum H.	8	99	12	0.62	0
Wu Z.	8	95	12	1.58	4
Ahn Y.H.	7	70	10	0.29	5
Chan E.H.W.	7	116	17	1.15	3
Li J.	7	123	18	0.95	1
Li Y.	7	94	13	1.84	4
Wang J.	7	223	32	0.67	2
Chen P.-H.	6	101	17	1.11	1
Chen Q.	6	83	14	0.61	1
Hwang B.-G.	6	150	25	1.94	0
Riley D.	6	191	32	1.40	0
Li B.	5	103	21	1.42	1
Liu Y.	5	71	14	1.22	0
Xu P.	5	99	20	1.42	5

Ye K.	5	73	15	1.82	3

However, Cole R. J. (11), Wallbaum H. (8), Hwang B.-G (6), Riley D. (6) and Liu Y. (5) had no collaborative researchers within their network, although they met the threshold of 5 articles and 65 citations. This is because their collaborators did not meet the threshold of 5 articles and 65 citations. In table 3, the top 4 most collaborative researchers include Darko A., Chan A.P.C., Zhang X., and Shen L. with total link strength (co-authored articles) of 12, 11,8, and 6 respectively. A correlation analysis showed that the total number of research articles has a significant positive correlation with total citations (r=0.48, p=0.01), at a confidence level of 95%. Thus, the contribution of an author (in terms of citation or an average number of citations) to the GB research is linearly related to the total number of articles the author produces. However, there was no significant correlation between the average citation of authors and average normalized citations (r=0.15, p=0.49).

Depending on the measure of productivity, the ranking of the researchers differs significantly. Based on overall impact (total citations), the top 4 researchers include Cole R.J., Shen L., Zhang X., Wang J., and Tam V.W.Y. whereas based on a number of articles, the top five productive authors include: Darko A., Zhang X., Chan A.P.C., Cole R.J., Gou Z. Based on average normalized citations, the most influential authors include Chan A.P.C., Darko A., Zhang X., Shen L., and Hwang B.-G. An interesting observation is that Ye K. (5) and Hwang B.-G. (6) produced relatively fewer publications but their average annual impact and influence (average normalized citations) in the GB research exceeded that of Cole R. J., Gou Z., and Zuo J., who contributed 11 articles each.

3.4.1 Article Citation Network Analysis

The number of citations an article records are normally used as one of the measures of the impact of the publication. For this reason, articles with higher citations are normally regarded as landmark publications, albeit not always the case. Pegging the minimum number of citations of an article to 65, 78 of 1147 research articles met the threshold. Only 46 of the 131 articles were connected to each other or one another (Fig. 6). These articles and their links to other articles are shown in Fig. 6. The influence of an article is assessed by its total citations, normalized citations and its links with other articles. In table 4, the top 20 most productive research articles in GB based on a number of citations are shown. These articles spanned from 1997 to 2011.

Based on a number of citations, the top five landmark articles include Wang *et al.* [69], Hoes *et al.* [70], Newsham *et al.* [71], Hill and Bowen [72] and Thormark [73]. Indeed, the multi-objective optimization model developed by Wang *et al.* [69] can be used to effectively assess life-cycle environmental impacts during the conceptual design stage of buildings. The classic study of Hoes *et al.* [70] noted that the behavior of occupants have a significant influence on the indoor environmental performance of GB and should be given due consideration at the design stage. As part of the early studies on sustainable construction, Hill and Bowen [72] developed an all-encompassing framework for pursuing sustainable construction targets. This group consists of 4 more recent and one older article.

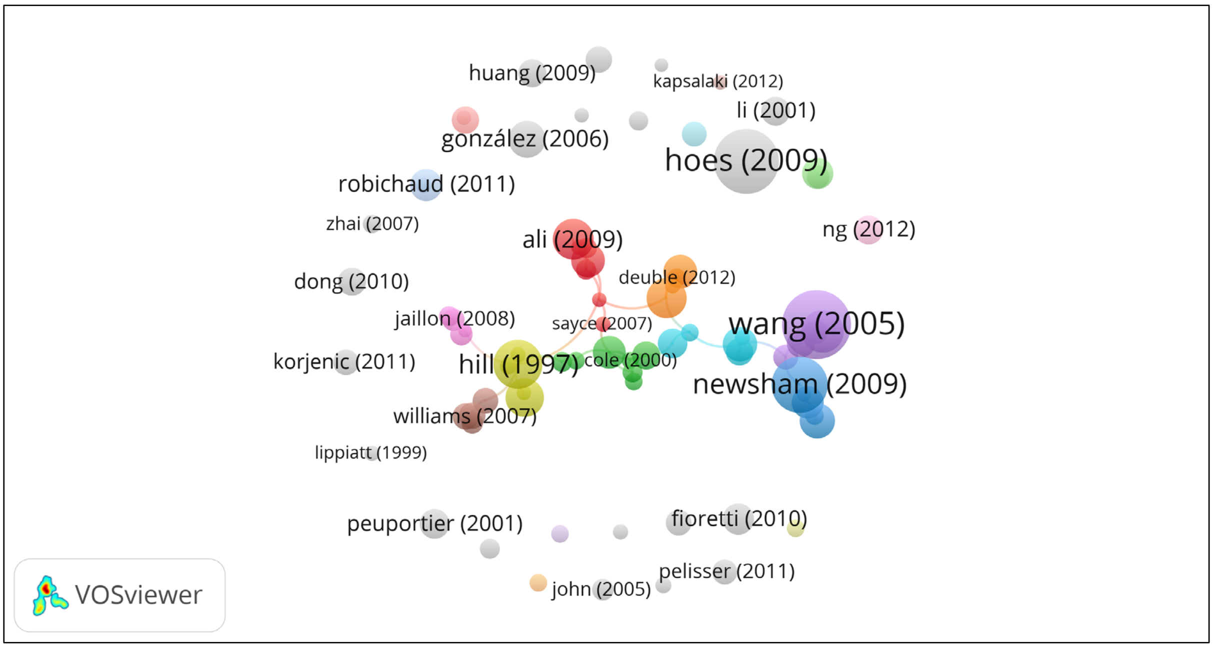

Fig. 6: Documents Citation Network Analysis

However, using the normalized citation metrics reveals a different pattern of the most productive articles. Under this metric, Thormark [73], González and García Navarro [74], Ardente *et al.* [75], Paul and Taylor [76] and Hoes *et al.* [70] are the most productive authors. Notably, the relatively recent articles appear to be the most productive. Using a quantitative approach, Thormark [73] demonstrated that appropriate selection of construction materials could reduce embodied carbon from 40% to 17% or conversely increased to 46%. Similarly, a hybrid of the life cycle and thermal simulation tool used for the evaluation of the environmental impact of construction materials found that making choices based on LCA can be slightly complicated [77].

Table 4: Most Productive Research Articles

Article	Title	citations	Norm. Citations	links
Wang *et al.* [69]	Applying multi-objective genetic algorithm in green building design optimization	320	3.75	4
Hoes *et al.* [70]	User behaviour in whole building simulation	302	6.43	0
Newsham *et al.* [71]	Do LEED-certified buildings save energy? Yes, but…	260	5.54	6
Hill and Bowen [72]	Sustainable Construction: Principles and a framework for attainment	229	1.88	9
Thormark [73]	The effect of material choice on the total energy need and recycling potential of a building	199	8.38	1
Ali and Al Nsairat [78]	Developing a green building assessment tool for developing countries-case of Jordan	189	4.03	1
Leaman and Bordass [79]	Are users more tolerant of ‘green’ buildings?	187	5.07	7

Azhar *et al.*[80]	Building Information Modelling for Sustainable Design and LEED® rating analysis	179	4.26	1
González and García Navarro [74]	Assessment of the decrease of CO_2 emissions in the construction field through the selection of materials: practical case study of the three houses of low environmental impact.	173	7.28	0
Juan *et al.* [81]	A hybrid decision support system for sustainable office building renovation and energy performance improvement	166	4.86	2
Crawley and Aho [82]	Building environmental assessment methods: applications and development trends	162	2.79	4
Cole [83]	Building environmental assessment methods: clarifying intentions	157	2.71	5
Holmes and Hacker [84]	Climate Change, thermal comfort and energy: meeting the design challenges of the 21^{st} century	156	4.23	1
Häkkinen and Belloni [85]	Barriers and Drivers for Sustainable Building	154	3.67	7
Robichaud and Anantatmula [3]	Greening project management practices for sustainable construction	150	3.57	3
Scofield [86]	Do LEED-certified buildings save energy? Not really	150	3.19	5
Fioretti *et al.* [87]	Green roof energy and water related performance in the Mediterranean climate	147	4.31	0
Ardente *et al.* [75]	Building energy performance: A LCA case study of Kenaf-fibres Insulation Board	146	6.95	1
Peuportier [77]	Life cycle assessment (LCA) applied to the comparative evaluation of single family houses in the French context	138	1.34	0
Paul and Taylor [76]	A Comparison of Occupant comfort and satisfaction between a green building and a conventional building	137	6.52	4

Examining the links among the 20 articles, a different pattern emerged. It is found that 9,7, 7, 6, 5, 5 of the 20 articles have cited Hill and Bowen [72], Leaman and Bordass [79], Häkkinen and Belloni [85], Newsham *et al.* [71], Cole [83] and Scofield [86], respectively. Again, two classic counteractive research studies are shown in table 4. By analyzing mean site energy intensity, Newsham *et al.* [71] found that LEED-certified building saves energy consumption between 18-39% per floor area whereas Scofield [86] examined 35 LEED-certified buildings and observed that in the context of both total site and source energy footprint, these buildings were not superior at all. The latter concluded that the conclusion of the former researchers was not plausible and generalizable. However, the two studies did not use the same projects and thus, the conclusion of the latter could still be debated based on differences in their buildings sample, scale, assumptions, and context. Nonetheless, the 20 articles in Table 4 constitute the most referenced publications in the GB research. A correlation analysis showed that there is no significant linear association between a number of citations and normalized citations ($r=0.14$, $p=0.55$) within the most productive research articles (table 4). Thus, the annual contribution of an article to the GB research community is not related to a number of citations of the article.

3.5 Active Countries in the GB research

Based on regions, some countries contribute higher than others in the GB research discourse. Whiles this depends on several factors, awareness of the most active countries in the GB research could foster future collaboration, promote the exchange of technologies and innovation as well as facilitate joint research funding programmes. In table 5, the contribution of the various countries to the GB research is assessed. Fig. 7 was generated by setting the minimum number of documents and citations of a country to 5 and 20, respectively. Of the 85 countries in the GB research, 38 met the thresholds. Effectively, about 44% (85 out of 193 or 195) of all countries in the world are involved in GB research. The size of a node (country) in Fig. 7 reflects the contribution of a country to the GB research discourse.

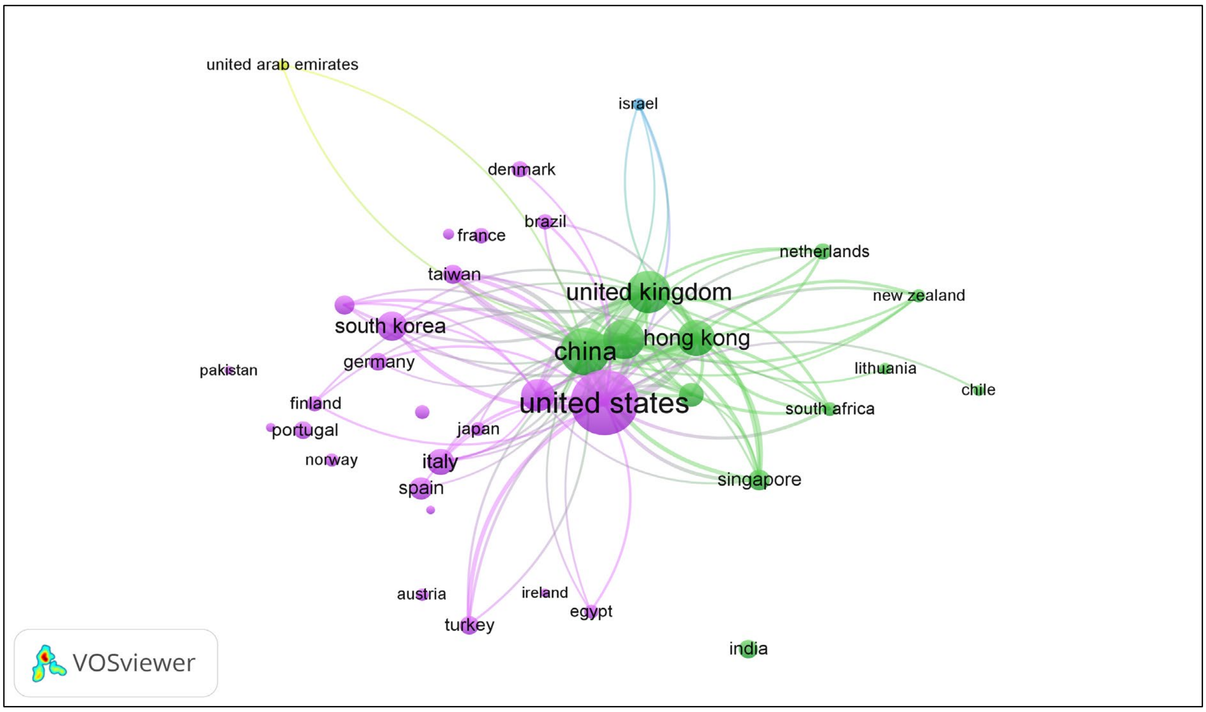

Fig. 7: Most Contributing Countries in the GB Research

For instance, the United States, United Kingdom, China, Hong Kong, Australia, and Canada are represented by bigger nodes than the rest of the territories. Also, 4 clusters of the most productive countries emerged. The United States, Singapore, South Africa, Lithuania, Chile, New Zealand, and the Netherlands belong to one cluster, represented by the green color. Other clusters are represented by different colors. There might be some geopolitical issues between and among countries but these clusters are generated based on collaboration, co-citations or similarity in research areas. Fig. 7 shows that GB research is conducted in developing, transitional and developed economies. Thus, it is not surprising that the area is witnessing an increasing pattern in research publications [3,6,14].

Table 5: Most Productive Countries in GB Research

Country	Global Classification*	No. of Articles	citations	Av. Citations	Norm. Citations	total link strength
United States	Global North	296	4802	16	210.96	905
United Kingdom	Global North	122	3103	25	126.64	734
China	Global South	155	2230	14	203.26	1028
Canada	Global North	71	2183	31	71.20	364
Hong Kong	Global North	88	1909	22	134.56	944
Australia	Global North	111	1481	13	131.03	827
Italy	Global North	46	935	20	59.42	118
Malaysia	Global South	39	740	19	70.68	138
Spain	Global North	34	720	21	43.40	54
Taiwan	Global North	25	715	29	33.33	197
Singapore	Global North	30	666	22	34.30	219
Netherlands	Global North	18	641	36	20.44	93
Germany	Global North	22	631	29	21.30	63
Sweden	Global North	25	528	21	29.97	107
Finland	Global North	16	521	33	20.59	70
Portugal	Global North	22	494	22	29.84	41
South Africa	Global South	13	450	35	14.04	141
France	Global North	16	375	23	16.19	30
India	Global South	23	355	15	29.1	23
South Korea	Global North	58	346	6	34.13	125

*Classifications were obtained from https://kups.ub.uni-koeln.de/6399/1/voices012015_concepts_of_the_global_south.pdf

Based on a number of articles and total citations, a consistent ranking pattern emerged. In the context of both metrics, the United States, United Kingdom, China, Australia, and Hong Kong are the most productive economies in the GB research. A slightly different ranking pattern is observed when analyzed through the lens of normalized citations. Under this, the United States (210.96), China (203.26), Hong Kong (134.56), Australia (131.03) and United Kingdom (126.64) are the influential contributing countries in the GB research. These are still the top five countries emerged based on the number of articles and total citations, but the ranking differs slightly. Their superior influences are expected because these economies have GB policies and rating systems. Thus, research studies were required to guide the implementation and evaluation of their progress. Apart from South America, each continent has at least one country actively contributing to the GB research discourse. The reported non-contribution from South America could be due to the language restriction (English) during the bibliometric data retrieval. The least contributing continent is Africa (only South Africa) and the most contributing continent is

Europe (9 countries), in terms of numbers. Effectively, the global north is making a greater national and regional commitment to the GB research than the global south.

3.6 Major Green Building Research Areas

The contents of research articles are mostly reflected in the keywords used in the titles and abstracts. Analyzing the keywords holistically can reveal the trends in the GB research domain. Su and Lee [46] noted that keywords can be sufficiently analyzed to identify research trends in a given subject. These keywords are mostly consistent with the contents of the article and research theme [49]. Although co-occurrence network of keywords is presented in Fig. 4, the network was generated using only author keywords. This section analyzed all the keywords within the 1147 research articles. The Binary counting method was selected based on best practice and the minimum number of occurrence of a term was set to 10. Out of 24840 keywords, 657 met the threshold. After a further computation of the relevance score of each keyword, the 60% (by default) most relevant terms were identified. Thus, 394 most relevant terms (Fig. 8) were critically analyzed and grouped into research areas. Using this approach, wider differences emerged between Fig. 4 and Fig. 8. A framework of the main research areas in GB is shown as Fig. 9.

GB Adoption and Implementation: Concerns about the energy consumption and adverse environmental impact of is driving the adoption of GB and green technologies. From the perspective stakeholders and experts, studies have examined the barriers [24,85,88–90], drivers [13,25,85,91], strategies and critical success factors in implementing GB. Evidence from developing and developed countries have emerged. However, the adoption rates in some parts of the world still appear sluggish and perfunctory. Among other factors, perceived higher cost of green building/technologies, inadequate green building expertise and stakeholders reluctance to accept the sustainable paradigm constitute some significant inertia to the adoption of green building [88,89,92]. Typically, in developing countries, the barriers to the adoption and implementation of GB manifest in the form of government, attitudinal, awareness, market, cost and risk factors [90]. However, the government is found to be pivotal as both a driver and a barrier to the adoption of green building technologies [13]. Amid the barriers and challenges, it is found that adoption of GB is driven by financial incentives, enforced GB policies, increased sensitization or awareness creation, and green building's rating/certification [90,93]. Darko et al.[25] mapped 64 drivers from the literature and classified them into individual, property, project, corporate and external-tier drivers. A similar study mapped the critical drivers from a reported 21 drivers in the literature [91]. From a Dutch construction perspective, it is found that public-private partnership is crucial to the development of green buildings [94]. While different factors motivate the adoption of GB, it is found that most countries promote GB due to reduced energy consumption, lower water footprint, improved environmental performance and superior indoor environmental conditions [91].

Fig. 8: Clusters of Main Research Areas

3.6.1 Brief Discussion of Main Research Areas

Darko et al. [13] deployed a partial least structural equation modeling to explore the dynamic interactions of the critical barriers, drivers and strategies for promoting the adoption of GB in a developing country. However, most studies identified pieces of critical barriers, drivers and promotion strategies in GB adoption [88,91,95]. Examining these issues in isolation is less likely going to make a useful contribution to policy formulation since these issues are complex and dynamic in reality. In this regard, the use of system dynamics approaches could offer more understanding of the behavior of the barriers and drivers under changing circumstances.

Attitude Assessment and Post-Occupancy Evaluation: Post-occupancy evaluation (POE) is a science of obtaining feedback through systematic periodic data collection and analysis on the whole lifecycle performance of a building in comparison with predefined performance criteria [96]. It provides a knowledge base for improving future GB designs, commissioning processes, end-user requirements and GB management procedures [96]. The assessment of the performance of green buildings and the accompanying attitude of the end users after some years of occupancy generate valuable evidence for improving future design and operation of buildings. For most cases, the experiences of end users or occupants could be used to ascertain the performance of these buildings [97]. Indeed, the behavior of occupants has a significant influence on energy consumption, energy management and indoor environmental performance of GB [70]. The data collection process for post-occupancy evaluation can be disreputably complicated [98], but the evidence therefrom are useful for improving future operations and construction of GB [97–99]. The use of only quantitative statistical techniques to measure the satisfaction level of end users of GB is found to be misleading [79] because qualitative interactions are more likely to reveal the tolerance levels of end users than the quantitative measures. Thus, a combination of both quantitative and qualitative methods could offer a more realistic approach to achieving the multifaced components in POE. Previous quantitative studies demonstrated some optimistic satisfactory perceptions of GB to end users [36] whereas mixed method studies showed that some occupants are totally dissatisfied with GB (e.g. the UK, USA etc.) whiles others registered higher satisfaction experiences (e.g. China, South Korea etc.) with GB [36]. Further, Newsham *et al.* [71] arrived at a conclusion similar to the latter after examining the experiences of 2545 end users GB whereas the study by Altomonte *et al.* [100] arrived at a conclusion similar to the former after analyzing 11243 responses. These varying conclusions are plausible for comparative purposes, but careful design, construction, and operation of conventional buildings could equally generate excellent GB performances and user experiences. Again, the behavior of end users could worsen the performance of GB's indoor environmental conditions [70,76]. The review revealed that the indoor environmental performances of green building have been extensively examined in POE research. Some studies have found that GB improves indoor air quality, ambient air quality, ventilation, natural lighting and thermal comfort [15,99] whereas others have demonstrated that GB is not superior in this regard [10,100]. Although green-certified buildings are expected to deliver higher satisfaction to end users, comparative studies have demonstrated that some end users tend to be highly dissatisfied due to a rather paradoxical high energy consumption of the green building [10,100]. A review of research on post-occupancy evaluation of GB have been conducted by Khoshbakht *et al.* [36]

Project Delivery and Management: Although many facets of green building construction and management mimic the stereotypes of conventional building, available evidence suggest that some significant differences in delivery and management exist between the construction, delivery, and management of the two forms of buildings [3]. Indeed, the higher initial cost, environmental and complex process of GB development apparently require a different project management model [101]. Hwang and Tan [102] noted that GB project management in Singapore are constrained by "high cost premium of a green building project", lack of communication and interest among project team members", "lack of expressed interest from client and market demand", "higher cost of implementing GB practices", and "lack of credible research on the benefits of GB". Hwang and Tan proposed strategies to address these management barriers. Li et al. [101] found that the successful management of GB projects require support from senior management, cooperation between architects and engineers, experienced designers and project managers, effective coordination and commitments of project stakeholders, adequate communication platforms, adequate budget and innovative financing initiative, involvement of designers and contractors at all stages, among other. Robichaud and Anantatmula [3] examined the project management processes of GB and conventional projects. The researchers argued that modifications must be made to develop green project management approaches in the green building discourse and thus, proposed a comprehensive green project management framework.

Stakeholder Management and Impact Analysis: At every stage of a building project, stakeholders influence and are influenced by the project. The impact of stakeholders on GB projects development is recognized from the planning stages through to construction, usage, post-occupancy evaluation, and eventual demolition stages [103]. The key GB stakeholders have been identified as owners, developers, designers, architects, contractors, industry practitioners, public or society and government [104,105]. Depending on the nature, scale, and type of the GB project, a complex network of stakeholders can be involved. These stakeholders usually have conflicting requirements. The ability to reconcile these competing needs is crucial for the success of GB development and retrofitting programmes [106]. Indeed, when the interests of these stakeholders (internal & external) are not given due consideration in the life cycle planning of GB projects, their impact could be very detrimental. Among other factors, Williams and Dair [89] noted that not making stakeholder appreciate sustainability measures have a negative influence on the adoption GB in the UK. Through a social network analysis, Yang *et al.* [105] noted that GBs are characterized by manifold stakeholder-related risk factors and noted that government as the biggest construction client is at the forefront of the GB building stakeholders. The impact of these stakeholders gets complex and multiplied when larger projects are involved. In such projects, risks of internal and external stakeholders tend to generate a complex web of challenges to GB development [104]. Li *et al.* [38] offer a review of the external stakeholders in GB projects.

Green Building Codes, Regulations and Policies: Codes and policies act as machinery which guide decision making towards more rational and defined outcomes. In the paradigm shift towards the adoption and implementation of GB, lack of GB codes and policies are identified as critical constraints [24]. As a result, research and policy commitment have been advanced to develop GB codes, incentives, regulations, and policies in different parts of the world. In Malaysia, government policies, green certification, and market strategy benefit motivations have been noted as critical incentives to green building adoption [40]. The role of government policies as a driver of green building adoption has been widely highlighted [8,13,93]. Policies and standards drive the market and orientate stakeholders to perceive green buildings as necessities [9]. In a North American study, studies show that policies, standards, and guidelines are the necessary machineries in the implementation of green building goals [12]. For instance, the green building policy of the US requires that fresh construction and major renovation projects be LEED-certified [10]. These policies set targets and threshold at the county, regional and national levels. However, DuBose *et al.* [11] argued that effective green building policies need to include inspirational, motivational, implementation and evaluation elements which range from awareness creation through to programme implementation and assessment of the performance of these policies, targets, and setbacks. Typically, GB policies and proxies are usually guided by environmental assessment techniques and benchmarks [107]. However, there is increasing need to guide such policies based on the holistic *triple bottom line* sustainability pillars because Doan *et al.* [32] found that the present state of mature rating tools such as BREEM, CASBEE, LEED, and Green Star NZ could not still assess GB projects in all aspects of sustainability. Doan et al. noted that the social and economic sustainability indicators in these rating tools require more improvement.

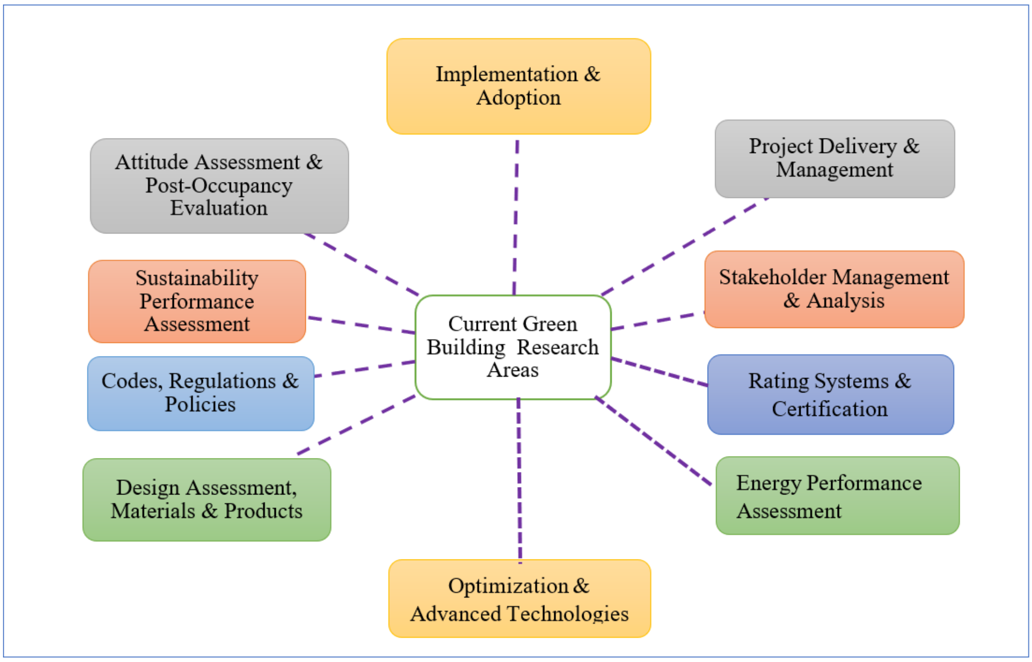

Fig. 9: Framework of Main Research Areas in Green Building

Sustainability Performance Assessment: the need to deliver healthy and responsible built environments have reinvigorated the holistic evaluation of the sustainability of GB. Issues of environmental impact, human health, water footprint, cost, and benefit analysis of GBs are increasingly becoming common in the literature. Studies have considered the environmental [84,108], economic [109] and social aspects of GB. It has been found that due to reduced water consumption (50%), construction solid generation (48%) and transportation (5%), LEED-certified buildings demonstrate reduced carbon footprint, compared to baseline figures of their conventional counterparts [108]. However, the uncertainties associated with varying climate change scenarios presents acute challenges in designing buildings now which will be capable of providing optimal environmental performance in the future [84]. For environmental impact of GBs, life cycle assessment tools have been developed [83]. Indeed, the nucleus of the GB transition is the need to improve energy efficiency and environmental performance of buildings [110]. Studies have examined the embodied carbon in GB construction materials, carbon emissions and the long-term effect of GB on climate change mitigation [33]. On a life cycle perspective, it has been demonstrated that the selection of appropriate GB materials and construction could effectively reduce CO_2 emissions [74]. Water consumption and footprint of GB construction is also becoming a major concern. Following the anecdotal claims that GB is characterized by lower water footprint [111], comparative studies of such potential in GB and conventional buildings have been examined. For instance, through a water conservation index, Cheng [111] demonstrated that GB saves about 20% of the water footprint, against the baseline figures of conventional buildings. The use of green technologies for water conservation, management, and treatment in Mediterranean climate resulted in minimization of the impact of stormwater runoff, in terms of volume, peak attenuation and time of concentration [87,112]. Studies have also demonstrated that the use of optimization models and stochastic programming in the design of GB can significantly reduce water footprint and energy consumption [113].

Nonetheless, all these sustainable designs and materials come along with different cost and benefits. Whiles GB is known to be relatively expensive than conventional buildings, life cycle cost and benefits analyses reveal contrary evidence [17,29]. Using optimization models, Assad *et al.* [109] examined the life cycle cost and benefits of GB in Egypt and demonstrated that the energy savings benefits of GB outperform the cost. In Turkey, Uğur and Leblebici [29] found that GB construction resulted in increased cost ranging from 8.27-10.7%, reduced the annual energy consumption of 31-40% but with a lengthened payback-period of 0.41 to 2.56 years. Yet, the energy savings potentials could outperform the combined additional cost and lengthened payback period. Ries *et al.* [17] demonstrated that GB improves productivity and reduces energy consumption by 25% and 30%, respectively. Thus, from economic and environmental perspectives, GB has demonstrated superior performance over conventional buildings in most research studies. However, there is a paucity of knowledge on the social sustainability performance of GB [32]. Evidence from this leg of the *triple bottom line* are crucial for solidifying sustainability claims in advocacy and promotion of GB.

Green Building Design, Materials and Products: In the sustainability discourse, sustainable design of buildings is becoming a fulcrum of design considerations [114]. The quality level of a construction project starts from the design stage. Indeed, the differences between GB and the conventional ones largely emanates from their designs [114]. The incorporation of sustainability into the design of conventional buildings eventually delivers GB. These designs are modified to improve energy performance, environmental impact, life cycle cost and reduce maintenance frequency [109]. The design of GB differs across various local climatic conditions. Thus, the design of GB in tropical climates varies from the design of GB in non-tropical climates. This has been recognized by practitioners and researchers. Notably, Alonso Monterde *et al.* [114] found that improved thermal comfort and reduced reduce the carbon footprint of buildings can be achieved if the design strategies contextually recognize the local climate. Increasingly, there is now the holistic consideration of construction safety risk during the design of GB [115]. Equally important to the design of GB is the choice of materials and products to be used in the construction stage. The design of buildings largely determines the cost and choice of materials. Thus, high-performance GB materials and products are required to complement the designs in delivering true GB [112]. It is reported that higher energy savings in GB could be achieved only if the energy saving potential of each component is assessed independently and holistically with all other building envelopes [116]. Therefore, the use of fewer green buildings components is unlikely to deliver actual GB (ibid).

Energy Performance Assessment: energy savings, efficiency, and improved energy performance constitute the core and traditional motive of the GB revolution [73]. The energy performance of GB has been extensively examined in different countries. In the United States, Newsham *et al.* [71] examined "100 LEED-certified commercial and institutional buildings" in the context of average site energy intensity and concluded that GB saves energy consumption in the range of 18-39% whereas, a counteractive study by Scofield [86] examined "35 LEED office buildings" in the context of both total site and source energy footprint and concluded that GB did not save energy consumptions. These varying conclusions on the energy performance of GB exist because of varying context, analytical protocols, and perspective of each study. Nonetheless, a wider consensus among researchers and practitioners have been reached that green buildings are far more energy efficient when carefully designed, constructed and operated. For instance, on a life-cycle basis, Assad *et al.* [109] found that GB saves at least 16.3% energy consumption and 50% on annual basis. In Japan, an empirical study demonstrated that GB not only saves energy consumption between 33-38% but also improves quality indoor environmental conditions as well as reducing operating cost and CO_2 emissions within the range of 26-32%.

Green Building Rating and Certification: from a sustainability perspective, the quality of a GB is normally assessed using rating metrics, systems, and certification. It is found that over 600 green rating tools are being implemented around the world [32]. Following the renewed commitment to the GB discourse, different studies on GB rating systems have emerged [29–32]. Preponderances of existing research treaties within this bracket focused on the customization, comparative assessment, environmental benefits appraisal and review of GB rating systems [6]. The commonly studied GB rating systems are identified as Leadership in Energy & Environmental Design (LEED), USA [117]; Building Research Establishment Environmental Assessment Methodology (BREEAM), UK; Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Japan; ITACA, Italy [30]; Green Standard for Energy and Environmental Design (G-SEED), South Korea; BEAM Plus, Hong Kong; Green Star NZ, New Zealand [32]; DGNB, Germany; etc. [31,32]. These systems are used to rate and certify the magnitude of sustainability in GBs. Whiles these can be adopted and applied in other countries, bespoke rating systems would be appropriate to reflect different climatic and socio-economic dynamics of the country concerned.

Optimization and Advanced technologies: As part of operations research in GB, the applications of geographic information systems (GIS), radio frequency identification (RFID), building information modeling (BIM), simulation, artificial neural networks and intelligent systems for optimizing the design, construction, and management of GB is gaining increasing attention. For instance, using a hybrid of GIS and decision support tools, Shad *et al.*[118] developed localized GB assessment tools for a city in Iran. A multi-objective genetic algorithm and optimization models have also been developed for life cycle environmental impact assessment at the conceptual design stage of GB [69,81]. The application of BIM in GB design, rating, energy consumption diagnosis and simulation of the environmental impact of GB construction is increasingly been reported [80]. By reviewing GB rating systems, Ali and Al Nsairat [78] deployed the Analytical Hierarchy Process (AHP) to develop a localized computer-based GB rating tool for Jordan. Although the application of robotics in the construction industry has been largely unsuccessful due to the problems of standardizations, the renewed commitment to modular construction could provide a brighter future for the application of robotics for optimization of the design, construction, and management of GB.

3.6.2 Knowledge Gaps and Future Research Consideration

Significant progress has been made in the GB research frontier but there is still more room for improvement as some facets have not received exhaustive research. The paper has identified some areas which may be considered in future studies. Firstly, GB codes, standards, regulations, policies and rating systems significantly affect the adoption of green buildings [32]. Notably, over 600 green rating tools are being implemented around the world [32]. As a result, some countries have been successful in rekindling the green building trajectory, but some countries still have far more failures than glories. Comparative studies of these rating tools could improve awareness of the strengths, coverage, and limitations of the tools. For instance, Zou [119] compared the targets, certification criteria, and standards of LEED and 3-Star in the context of China. Doan et al. [32] compared the strengths and weaknesses of BREEAM, CASBEE, LEED and Green Star NZ and found that none could assess the project in all aspects of sustainability. Thus, the paper recommends that future studies could conduct a *comparative assessment of some the mature and infant rating tools* to provide evidence towards improving these tools.

Again, the barriers and drivers of GB have been identified to be different in developing and developed economies [91]. The critical success factors and strategies for promoting GB were also found to be different in developing and developed countries [97]. Thus, the review found that the barriers, drivers and critical success factors in the adoption and implementation of GB have been extensively studied. It is found that Darko et al. [13] explored the barriers, drivers and promotion strategies for GB adoption in Ghana using a Partial Least Structural Modelling equation. However, preponderances of the prevailing research treaties examined these barriers, drivers and success factors based on linearity assumptions and as if they existed completely in isolation. In reality however, such linearity is hardly meaningful in explaining the dynamic and complex behaviour of these systems. Thus, the study recommends that future studies may adopt complexity science theory and systems thinking philosophy in exploring the dynamic and interdependent behaviour of these issues. Tools such as total interpretive structural modeling, structural equation modeling, systems dynamics, among others are useful in achievingng the proposed issue.

Moreover, Robichaud and Anantatmula [3] found that the implementation of GB needs to be implemented by learning from best management practices to achieve higher success. This could be achieved by learning from the barriers, drivers, critical success factors and effective strategies in countries with wider adoption of GB [65]. Meanwhile, these evidence have been widely reported in both developing and developed countries. Frameworks are therefore required to guide the implementation of GB. For instance, Sharif *et al.* [120] proposed a framework for implementing green building in government projects in Malaysia. Also, Darko *et al.* [13] proposed a framework for promoting the adoption of GB in Ghana based a structural model of barriers, drivers and promotion strategies. However, the review showed that no study has proposed a *best practice framework for implementing green building* in developing and developed countries. Thus, the paper recommends that future studies may draw on shreds of evidence on the successes and failures factors of GB projects to develop *best practice frameworks for implementing GBs*.

Finally, the financing mechanisms for green building differ from the financing strategies of conventional building [90]. For instance, in Australia, the application for GB financing requires a more robust assessment of the cost, benefits, feasibility and uncertainty assessment [121]. Thus, effective assessment frameworks are required to simplify the funding assessment procedure. Meanwhile, Shan *et al*. [122] conducted a global review of sustainable construction project financing and found that the barriers, benefits, drivers, knowledge-based support systems and best practice framework for effectively implementing financing vehicles for GB are not well-understood. Thus, future studies could critically examine *GB financing initiatives by exploring these issues.*

4. Conclusion

Increasing concerns about the energy and environmental performance of the built environment have become crucial in the sustainable development discourse. Green buildings have emerged as a sustainable building option over the past couple of decades and have resulted in increasing research publications in the area. This study examined the research trends on green buildings in construction journals using a scientometric review. The study recruited bibliometric data of 1147 research articles published in 14 top construction journals between 1992 and 2018. The analysis showed that green building research witnessed a steady growth within the 20-year period, with a significant marginal increase in each year. However, sinusoidal trends of growth were recorded between 2001 and 2011. This marked the period of skepticism on the importance and viability of green building.

The analysis also showed that *Building and Environment (4857); Energy and Buildings (4550); Building Research and Information (3069); Journal of Cleaner Production (198); and Construction Management and Economics (1050)* are the 5 top most cited and influential research outlets in green building research. Indeed, these journals have published between 36 and 198 research articles. Based on frequency of co-occurrence and total link strength, the analysis showed that "sustainability", "green building", "sustainable construction", "green buildings", "sustainable development", "sustainable building", "LEED", "energy efficiency", "life cycle assessment" and "construction industry" were the most used author keywords in the green building research. This reinforces the validity of the keywords used in retrieving the relevant articles. A co-authorship analysis showed that Darko A. (12), Chan A.P.C. (11), Zhang X. (8) and Shen L. (6) are the four most collaborative researchers in green building research. The analysis also showed that 20 articles have been cited between 137 and 320 times from 1992 to 2018. The top 5 of these articles included: Wang *et al*. [69], Hoes *et al.* [70], Newsham *et al.* [71], Hill and Bowen [72], and Thormark [73].

Regional analysis showed that 85 (44%) of the global 193 or 195 countries are involved in green building research. This indicates that green building has wider recognition. On a national basis, the United States (296), China (155), United Kingdom (122), Australia (111) and Hong Kong (88) are the top five most contributing economies. Based on citations, the United States (4802), United Kingdom (3103), China (2230), Canada (2183) and Hong Kong (1909) are the most influential countries in green building research. On the continental basis, Europe has the most countries in the green building research, whereas South America has the least. Generally, the global north makes a higher contribution to the green building research than the global south.

Much progress has been made on green building research. We identified ten (10) broad research areas emerged from the thematic content analysis and qualitative discussion of the literature: green building adoption and implementation; attitude assessment and post-occupancy evaluation; project delivery and management; stakeholder management and impact analysis; green building codes, regulations and policies; sustainability performance assessment; green building design, materials and products; energy performance assessment; green building rating and certification; and optimization and advanced technologies. The paper recognized that there is subjectivity in classifying the GB papers into research frontiers but since we relied on the most cited 394 indexed keywords, such subjectivity was minimized and could be verified by a bibliographer. Nonetheless, some areas still require further research to advance our understanding. These include comparative research studies on green building policies and rating tools; application of complexity theory and system dynamics; best practice framework for green buildings implementation; and assessment of green building financing initiatives.

Thus, the study offers holistic background information on green building to researchers, graduate students, stakeholders, industry, government, energy policymakers, journals and funding bodies. The research gaps offered in the study could be investigated further by graduate students and researchers alike. Stakeholders could use this information to guide decision making. The government may find the information useful in policy formulation and research prioritization. Industry professionals are offered the achievements of research in different parts of the world, which could promote innovation. Policymakers could use this study as a repertoire to identify key areas for further investigations in policy-making discourse. Research outlets could identify potential reviewers in the green building research whereas funding agencies are offered the opportunity to identify research areas for prioritization and regions for joint funding programmes. However, the results of the study should be interpreted in light of some limitations. First, the authors could not manually read through all the 1147 research articles recruited in the study and thus, some critical articles could have been missed in the qualitative discussion. Nonetheless, due diligence was undertaken to guarantee sufficient coverage of all relevant articles. Again, the discussions were not in-depth enough due to space constraints. Finally, the scientometric analysis only considered articles published in 14 construction journals and thus, relevant papers in other journals could not be captured within the quantitative assessment.

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References

[1] R. Cassidy, White Paper on Sustainability: A report on the green building movement., Reed Bus. Information, Build. Des. Constr. (2003) 1–48. https://www.bdcnetwork.com/sites/bdc/files/BD%2BC 2003 White Paper on Sustainability.pdf.

[2] U.S. Green Building Council, Building momentum: National trends and prospects for high-performance green buildings, Washington, D.C., 2003.

[3] L.B. Robichaud, V.S. Anantatmula, Greening project management practices for sustainable construction, J. Manag. Eng. 27 (2011) 48–57.

[4] Office of the Federal Environmental Executive, The Federal Commitment to Green Building: Experiences and Expectations, CreateSpace Publishing, Washington, DC, 2014. https://www.barnesandnoble.com/w/the-federal-commitment-to-green-building-the-office-of-the-federal-environmental/1120789211.

[5] D.H.W. Li, L. Yang, J.C. Lam, Zero energy buildings and sustainable development implications - A review, Energy. 54 (2013) 1–10. doi:10.1016/j.energy.2013.01.070.

[6] A. Darko, A.P.C. Chan, Critical analysis of green building research trend in construction journals, Habitat Int. 57 (2016) 53–63. doi:10.1016/j.habitatint.2016.07.001.

[7] USGBC Research Committee, A National Green Building Research Agenda, United States, 2008. https://www.usgbc.org/sites/default/files/Docs3402.pdf.

[8] K. Williams, C. Dair, What Is Stopping Sustainable Building in England? Barriers Experienced by Stakeholders in Delivering Sustainable Developments, Sustain. Dev. 15 (2007) 135–147. doi:10.1002/sd.308.

[9] Z. Gou, S.S.-Y. Lau, D. Prasad, Market Readiness and Policy Implications for Green Buildings: Case Study From Hong Kong, J. Green Build. 8 (2013) 162–173. doi:10.3992/jgb.8.2.162.

[10] Q. Chen, L. Kleinman, A. Dial, Energy Perfromance of Campus LEED® Buildings: Implications for Green Building And Energy Policy, J. Green Build. 10 (2015) 137–160. doi:10.3992/jgb.10.3.137.

[11] J.R. DuBose, S.J. Bosch, A.R. Pearce, Analysis of state wide green building policies, J. Green Build. 2 (2007) 161–177. http://vt.summon.serialssolutions.com/link/0/eLvHCXMwY2BQMDOyTAWN3JsCC_8Us7QkQ8MkkzSzZCDDxCIl2TANZcc7UmnuJsqg7eYa4uyhi1wFxBdAjl2IB8-amRuADmQHnxIjxsCbCFoFnlcC3i2WwrdSpKX8I6t3XvPk62oNF38sAgBPVCgM.

[12] A.F. Cupido, B.W. Baetz, A. Pujari, S. Chidiac, Evaluating Institutional Green Building Policies: A Mixed-Methods Approach, J. Green Build. 5 (2010) 115–131. doi:10.3992/jgb.5.1.115.

[13] A. Darko, A.P.C. Chan, Y. Yang, M. Shan, B.J. He, Z. Gou, Influences of barriers, drivers, and promotion strategies on green building technologies adoption in developing countries: The Ghanaian case, J. Clean. Prod. 200 (2018) 687–703. doi:10.1016/j.jclepro.2018.07.318.

[14] C.J. Kibert, The next generation of sustainable construction, Build. Res. Inf. 35 (2007) 595–601. doi:10.1080/09613210701467040.

[15] O. Balaban, J.A. Puppim de Oliveira, Sustainable buildings for healthier cities: assessing the co-benefits of green buildings in Japan, J. Clean. Prod. 163 (2017) S68–S78. doi:10.1016/j.jclepro.2016.01.086.

[16] O. Ortiz, F. Castells, G. Sonnemann, Sustainability in the construction industry: A review of recent developments based on LCA, Constr. Build. Mater. 23 (2009) 28–39. doi:10.1016/j.conbuildmat.2007.11.012.

[17] R. Ries, M.M. Bilec, N.M. Gokhan, K.L. Needy, The economic benefits of green buildings: A comprehensive case study, 2006. doi:10.1080/00137910600865469.

[18] R. Axelsson, P. Angelstam, M. Elbakidze, N. Stryamets, K.-E. Johansson, Sustainable Development and Sustainability: Landscape Approach as a Practical Interpretation of Principles and Implementation Concepts, J. Landsc. Ecol. 4 (2011) 5–30. doi:10.2478/v10285-012-0040-1.

[19] T.O. Olawumi, D.W.M. Chan, A scientometric review of global research on sustainability and sustainable development, J. Clean. Prod. 183 (2018) 231–250. doi:10.1016/j.jclepro.2018.02.162.

[20] M.R. Hosseini, I. Martek, E.K. Zavadskas, A.A. Aibinu, M. Arashpour, N. Chileshe, Critical evaluation of off-site construction research: A Scientometric analysis, Autom. Constr. 87 (2018) 235–247. doi:10.1016/j.autcon.2017.12.002.

[21] J. Zuo, Z.Y. Zhao, Green building research-current status and future agenda: A review, Renew. Sustain. Energy Rev. 30 (2014) 271–281. doi:10.1016/j.rser.2013.10.021.

[22] W.M. Cohen, R.R. Nelson, J.P. Walsh, Links and Impacts: The Influence of Public Research on Industrial R&D, Manage. Sci. 48 (2002) 1–23. doi:10.1287/mnsc.48.1.1.14273.

[23] X. Huo, A.T.W. Yu, Analytical Review of Green Building Development Studies, J. Green Build. 12 (2017) 130–148. doi:10.3992/1943-4618.12.2.130.

[24] A. Darko, A.P.C. Chan, Review of Barriers to Green Building Adoption, Sustain. Dev. 25 (2017) 167–179. doi:10.1002/sd.1651.

[25] A. Darko, C. Zhang, A.P.C. Chan, Drivers for green building: A review of empirical studies, Habitat Int.

60 (2017) 34–49. doi:10.1016/j.habitatint.2016.12.007.

[26] P.N. Lemougna, U.F.C. Melo, E. Kamseu, A.B. Tchamba, Laterite based stabilized products for sustainable building applications in tropical countries: Review and prospects for the case of Cameroon, Sustainability. 3 (2011) 293–305. doi:10.3390/su3010293.

[27] P. De Luca, I. Carbone, J.B. Nagy, Green Building Materials : a Review of State of the Art Studies of Innovative Materials, (2017) 141–162.

[28] H. Wang, P.-C. Chiang, Y. Cai, C. Li, X. Wang, T.-L. Chen, S. Wei, Q. Huang, Application of Wall and Insulation Materials on Green Building: A Review, Sustainability. 10 (2018) 3331. doi:10.3390/su10093331.

[29] L.O. Uğur, N. Leblebici, An examination of the LEED green building certification system in terms of construction costs, Renew. Sustain. Energy Rev. 81 (2018) 1476–1483. doi:10.1016/j.rser.2017.05.210.

[30] B. Mattoni, C. Guattari, L. Evangelisti, F. Bisegna, P. Gori, F. Asdrubali, Critical review and methodological approach to evaluate the differences among international green building rating tools, Renew. Sustain. Energy Rev. 82 (2018) 950–960. doi:10.1016/j.rser.2017.09.105.

[31] N. Lee, S. Tae, Y. Gong, S. Roh, Integrated building life-cycle assessment model to support South Korea's green building certification system (G-SEED), Renew. Sustain. Energy Rev. 76 (2017) 43–50. doi:10.1016/j.rser.2017.03.038.

[32] D.T. Doan, A. Ghaffarianhoseini, N. Naismith, T. Zhang, A. Ghaffarianhoseini, J. Tookey, A critical comparison of green building rating systems, Build. Environ. 123 (2017) 243–260. doi:10.1016/j.buildenv.2017.07.007.

[33] Y. Dutil, D. Rousse, G. Quesada, Sustainable buildings: An ever evolving target, Sustainability. 3 (2011) 443–464. doi:10.3390/su3020443.

[34] M. Glaumann, T. Malm, J. Larsson, Evaluation of green buildings in Sweden, Build. Res. Inf. 27 (1999) 276–285. doi:10.1080/096132199369381.

[35] N. Kohler, The relevance of Green Building Challenge: An observer's perspective, Build. Res. Inf. 27 (1999) 309–320. doi:10.1080/096132199369426.

[36] M. Khoshbakht, Z. Gou, Y. Lu, X. Xie, J. Zhang, Are green buildings more satisfactory? A review of global evidence, Habitat Int. 74 (2018) 57–65. doi:10.1016/j.habitatint.2018.02.005.

[37] J. Zuo, S. Pullen, R. Rameezdeen, H. Bennetts, Y. Wang, G. Mao, Z. Zhou, H. Du, H. Duan, Green building evaluation from a life-cycle perspective in Australia: A critical review, Renew. Sustain. Energy Rev. 70 (2017) 358–368. doi:10.1016/j.rser.2016.11.251.

[38] Y.Y. Li, P.-H. Chen, D.A.S. Chew, C.C. Teo, R.G. Ding, Exploration of Critical External Partners of Architecture/Engineering/Construction (Aec) Firms for Delivering Green Building Projects in Singapore, J. Green Build. 7 (2012) 193–209. doi:10.3992/1943-4618-7.3.193.

[39] A.N. Nielsen, R.L. Jensen, T.S. Larsen, S.B. Nissen, Early stage decision support for sustainable building renovation - A review, Build. Environ. 103 (2016) 165–181. doi:10.1016/j.buildenv.2016.04.009.

[40] I.J. Onuoha, G.U. Aliagha, M.S.A. Rahman, Modelling the effects of green building incentives and green building skills on supply factors affecting green commercial property investment, Renew. Sustain. Energy Rev. 90 (2018) 814–823. doi:10.1016/j.rser.2018.04.012.

[41] L. Zhang, J. Wu, H. Liu, Turning green into gold: A review on the economics of green buildings, J. Clean.

Prod. 172 (2018) 2234–2245. doi:10.1016/j.jclepro.2017.11.188.

[42] Y. Zhang, J. Wang, F. Hu, Y. Wang, Comparison of evaluation standards for green building in China, Britain, United States, Renew. Sustain. Energy Rev. 68 (2017) 262–271. doi:10.1016/j.rser.2016.09.139.

[43] M.P. Markoulli, C.I.S.G. Lee, E. Byington, W.A. Felps, Mapping Human Resource Management: Reviewing the field and charting future directions, Hum. Resour. Manag. Rev. 27 (2017) 367–396. doi:10.1016/j.hrmr.2016.10.001.

[44] M.J. Cobo, A.G. López-Herrera, E. Herrera-Viedma, F. Herrera, Science Mapping Software Tools: Review, Analysis, and Cooperative Study AmongTools, J. Am. Soc. Inf. Sci. Technol. 62 (2011) 1382–1402. doi:10.1002/asi.

[45] R.J. w. Tijssen, A.F. j. Van Raan, Mapping Changes in Science and Technology: Bibliometric Co-Occurrence Analysis of the R&D Literature, Eval. Rev. 18 (1994) 98–115. doi:10.1177/0193841X9401800110.

[46] H.N. Su, P.C. Lee, Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in Technology Foresight, Scientometrics. 85 (2010) 65–79. doi:10.1007/s11192-010-0259-8.

[47] W.W. Hood, C.S. Wilson, The literature of bibliometrics, scientometrics, and informetrics, Scientometrics. 52 (2001) 291–314. doi:10.1023/A:101791992.

[48] N.J. van Eck, L. Waltman, Software survey: VOSviewer, a computer program for bibliometric mapping, Scientometrics. 84 (2010) 523–538. doi:10.1007/s11192-009-0146-3.

[49] N.J. van Eck, L. Waltman, Visualizing bibliometric networks, in: D.W. Ding, R. Rousseau (Ed.), Meas. Sch. Impact Methods Pract., Springer International Publishing, Cham, 2014: pp. 285–320. doi:10.1007/978-3-319-10377-8.

[50] R. Jin, S. Gao, A. Cheshmehzangi, E. Aboagye-Nimo, A Holistic Review of off-site Construction Literature Published between 2008 and 2018, J. Clean. Prod. 202 (2018) 1202–1219. doi:10.1016/j.jclepro.2018.08.195.

[51] J.Y. Park, Z. Nagy, Comprehensive analysis of the relationship between thermal comfort and building control research - A data-driven literature review, Renew. Sustain. Energy Rev. 82 (2018) 2664–2679. doi:10.1016/j.rser.2017.09.102.

[52] Q. He, G. Wang, L. Luo, Q. Shi, J. Xie, X. Meng, Mapping the managerial areas of Building Information Modeling (BIM) using scientometric analysis, Int. J. Proj. Manag. 35 (2017) 670–685. doi:10.1016/j.ijproman.2016.08.001.

[53] J. Song, H. Zhang, W. Dong, A review of emerging trends in global PPP research: analysis and visualization, Scientometrics. 107 (2016) 1111–1147. doi:10.1007/s11192-016-1918-1.

[54] Y. Hong, D.W.M. Chan, Research trend of joint ventures in construction: a two-decade taxonomic review, J. Facil. Manag. 12 (2014) 118–141. doi:10.1108/JFM-04-2013-0022.

[55] L.I. Meho, Y. Rogers, Citation Counting, Citation Ranking, and h-Index of Human-Computer Interaction Researchers: A Comparison of Scopus and Web of Science, J. Am. Soc. Inf. Sci. Technol. 59 (2008) 1711–1726. doi:10.1002/asi.20874.

[56] L. Butler, M.S. Visser, Extending citation analysis to non-source items, Scientometrics. 66 (2006) 327–343. doi:10.1007/s11192-006-0024-1.

[57] R. Santos, A.A. Costa, A. Grilo, Bibliometric analysis and review of Building Information Modelling

literature published between 2005 and 2015, Autom. Constr. 80 (2017) 118–136. doi:10.1016/j.autcon.2017.03.005.
[58] W. Yi, A.P.C. Chan, Critical Review of Labor Productivity Research in Construction Journals, J. Manag. Eng. 30 (2013) 214–225. doi:10.1061/(ASCE)ME.1943-5479.0000194.
[59] C.J. Kibert, Establishing Principles and a Model for Sustainable Construction, in: Proc. First Int. Conf. CIB TG 16 Sustain. Constr., Tampa, Florida, USA,November 6-9, 1994: pp. 3–12.
[60] M. Oraee, M.R. Hosseini, E. Papadonikolaki, R. Palliyaguru, M. Arashpour, Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review, Int. J. Proj. Manag. 35 (2017) 1288–1301. doi:10.1016/j.ijproman.2017.07.001.
[61] M.R. Hosseini, I. Martek, E.K. Zavadskas, A.A. Aibinu, M. Arashpour, N. Chileshe, Critical evaluation of off-site construction research: A Scientometric analysis, Autom. Constr. 87 (2018) 235–247. doi:10.1016/j.autcon.2017.12.002.
[62] X. Zhao, A scientometric review of global BIM research: Analysis and visualization, Autom. Constr. 80 (2017) 37–47. doi:10.1016/j.autcon.2017.04.002.
[63] M.R. Hosseini, I. Martek, E.K. Zavadskas, A.A. Aibinu, M. Arashpour, N. Chileshe, Critical evaluation of off-site construction research: A Scientometric analysis, Autom. Constr. 87 (2018) 235–247. doi:10.1016/j.autcon.2017.12.002.
[64] Y. Li, X. Chen, X. Wang, Y. Xu, P.H. Chen, A review of studies on green building assessment methods by comparative analysis, Energy Build. 146 (2017) 152–159. doi:10.1016/j.enbuild.2017.04.076.
[65] P. Xu, E.H.W. Chan, P.T.I. Lam, a Conceptual Framework for Delivering Sustainable Building Energy Efficency Retrofit Using the Energy Performance Contracting (Epc) in China, J. Green Build. 8 (2013) 177–190. doi:10.3992/jgb.8.1.177.
[66] P. Xu, E.H.W. Chan, ANP model for sustainable Building Energy Efficiency Retrofit (BEER) using Energy Performance Contracting (EPC) for hotel buildings in China, Habitat Int. 37 (2013) 104–112. doi:10.1016/j.habitatint.2011.12.004.
[67] P. Xu, E.H.W. Chan, Q.K. Qian, Success factors of energy performance contracting (EPC) for sustainable building energy efficiency retrofit (BEER) of hotel buildings in China, Energy Policy. 39 (2011) 7389–7398. doi:10.1016/j.enpol.2011.09.001.
[68] P. Xu, E.H.W. Chan, H.J. Visscher, X. Zhang, Z. Wu, Sustainable building energy efficiency retrofit for hotel buildings using EPC mechanism in China: Analytic Network Process (ANP) approach, J. Clean. Prod. 107 (2015) 378–388. doi:10.1016/j.jclepro.2014.12.101.
[69] W. Wang, R. Zmeureanu, H. Rivard, Applying multi-objective genetic algorithms in green building design optimization, Build. Environ. 40 (2005) 1512–1525. doi:10.1016/j.buildenv.2004.11.017.
[70] P. Hoes, J.L.M. Hensen, M.G.L.C. Loomans, B. de Vries, D. Bourgeois, User behavior in whole building simulation, Energy Build. 41 (2009) 295–302. doi:10.1016/j.enbuild.2008.09.008.
[71] G.R. Newsham, S. Mancini, B.J. Birt, Do LEED-certified buildings save energy? Yes, but..., Energy Build. 41 (2009) 897–905. doi:10.1016/j.enbuild.2009.03.014.
[72] R.C. Hill, P.A. Bowen, Sustainable construction: Principles and a framework for attainment, Constr. Manag. Econ. 15 (1997) 223–239. doi:10.1080/014461997372971.
[73] C. Thormark, The effect of material choice on the total energy need and recycling potential of a building,

Build. Environ. 41 (2006) 1019–1026. doi:10.1016/j.buildenv.2005.04.026.
[74] M.J. González, J. García Navarro, Assessment of the decrease of CO2 emissions in the construction field through the selection of materials: Practical case study of three houses of low environmental impact, Build. Environ. 41 (2006) 902–909. doi:10.1016/j.buildenv.2005.04.006.
[75] F. Ardente, M. Beccali, M. Cellura, M. Mistretta, Building energy performance: A LCA case study of kenaf-fibres insulation board, Energy Build. 40 (2008) 1–10. doi:10.1016/j.enbuild.2006.12.009.
[76] W.L. Paul, P.A. Taylor, A comparison of occupant comfort and satisfaction between a green building and a conventional building, Build. Environ. 43 (2008) 1858–1870. doi:10.1016/j.buildenv.2007.11.006.
[77] B.L.P. Peuportier, Life cycle assesment applied to the comparative evaluation of single family houses in the french context, Energy Build. 33 (2001) 443–450. doi:10.1134/S0020168508120169.
[78] H.H. Ali, S.F. Al Nsairat, Developing a green building assessment tool for developing countries - Case of Jordan, Build. Environ. 44 (2009) 1053–1064. doi:10.1016/j.buildenv.2008.07.015.
[79] A. Leaman, B. Bordass, Are users more tolerant of “green” buildings?, Build. Res. Inf. 35 (2007) 662–673. doi:10.1080/09613210701529518.
[80] S. Azhar, W.A. Carlton, D. Olsen, I. Ahmad, Building information modeling for sustainable design and LEED®rating analysis, Autom. Constr. 20 (2011) 217–224. doi:10.1016/j.autcon.2010.09.019.
[81] Y.K. Juan, P. Gao, J. Wang, A hybrid decision support system for sustainable office building renovation and energy performance improvement, Energy Build. 42 (2010) 290–297. doi:10.1016/j.enbuild.2009.09.006.
[82] D. Crawley, I. Aho, Building environmental assessment methods: applications and development trends, Build. Res. Inf. 27 (1999) 300–308. doi:10.1080/096132199369417.
[83] R.J. Cole, Building environmental assessment methods : clarifying intentions, Build. Res. Inf. 27 (1999) 230–246. doi:10.1080/096132199369354.
[84] M.J. Holmes, J.N. Hacker, Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century, Energy Build. 39 (2007) 802–814. doi:10.1016/j.enbuild.2007.02.009.
[85] T. Häkkinen, K. Belloni, Barriers and drivers for sustainable building, Build. Res. Inf. 39 (2011) 239–255. doi:10.1080/09613218.2011.561948.
[86] J.H. Scofield, Do LEED-certified buildings save energy? Not really..., Energy Build. 41 (2009) 1386–1390. doi:10.1016/j.enbuild.2009.08.006.
[87] R. Fioretti, A. Palla, L.G. Lanza, P. Principi, Green roof energy and water related performance in the Mediterranean climate, Build. Environ. 45 (2010) 1890–1904. doi:10.1016/j.buildenv.2010.03.001.
[88] A.P.C. Chan, A. Darko, E.E. Ameyaw, D.-G. Owusu-Manu, Barriers Affecting the Adoption of Green Building Technologies, J. Manag. Eng. 33 (2015) 1–12. doi:10.1061/(ASCE)ME.1943-5479.0000507.
[89] K. Williams, C. Dair, What Is Stopping Sustainable Building in England? Barriers Experienced by Stakeholders in Delivering Sustainable Developments Katie, Sustain. Dev. 15 (2007) 135–147. doi:10.1002/sd.
[90] A.P.C. Chan, A. Darko, A.O. Olanipekun, E.E. Ameyaw, Critical barriers to green building technologies adoption in developing countries: The case of Ghana, J. Clean. Prod. 172 (2018) 1067–1079. doi:10.1016/j.jclepro.2017.10.235.
[91] A. Darko, A.P.C. Chan, D.G. Owusu-Manu, E.E. Ameyaw, Drivers for implementing green building

technologies: An international survey of experts, J. Clean. Prod. 145 (2017) 386–394. doi:10.1016/j.jclepro.2017.01.043.

[92] S.D. Djokoto, J. Dadzie, E. Ohemeng-Ababio, Barriers to Sustainable Construction in the Ghanaian Construction Industry: Consultants Perspectives, J. Sustain. Dev. 7 (2014) 134–143. doi:10.5539/jsd.v7n1p134.

[93] A. Darko, A.P.C. Chan, Strategies to promote green building technologies adoption in developing countries: The case of Ghana, Build. Environ. 130 (2018) 74–84. doi:10.1016/j.buildenv.2017.12.022.

[94] B.A.G. Bossink, A Dutch public-private strategy for innovation in sustainable construction, Constr. Manag. Econ. 20 (2002) 633–642. doi:10.1080/01446190210163534.

[95] A.P.C. Chan, A. Darko, E.E. Ameyaw, Strategies for promoting green building technologies adoption in the construction industry-An international study, Sustain. 9 (2017) 1–18. doi:10.3390/su9060969.

[96] K. Hadjri, C. Crozier, Post-occupancy evaluation : purpose , benefits and barriers, Facilities. 1/2 (2014) 21–33. doi:10.1108/02632770910923063.

[97] R.J. Cole, Green buildings and their occupants: A measure of success, Build. Res. Inf. 38 (2010) 589–593. doi:10.1080/09613218.2010.484168.

[98] Z. Brown, R.J. Cole, Influence of occupants' knowledge on comfort expectations and behaviour, Build. Res. Inf. 37 (2009) 227–247. doi:10.1080/09613210902794135.

[99] G.R. Newsham, B.J. Birt, C. Arsenault, A.J.L. Thompson, J.A. Veitch, S. Mancini, A.D. Galasiu, B.N. Gover, I.A. Macdonald, G.J. Burns, Do 'green' buildings have better indoor environments? New evidence, Build. Res. Inf. 41 (2013) 415–434. doi:10.1080/09613218.2013.789951.

[100] S. Altomonte, S. Schiavon, M.G. Kent, G. Brager, Indoor environmental quality and occupant satisfaction in green-certified buildings, Build. Res. Inf. 0 (2017) 1–20. doi:10.1080/09613218.2018.1383715.

[101] Y.Y. Li, P. Chen, S.A.D. Chew, C.C. Teo, R.G. Ding, Critical Project Management Factors of AEC Firms for Delivering Green Building Projects in Singapore, J. Constr. Eng. Manag. 137 (2011) 1153–1163. doi:10.1061/(ASCE)CO.1943-7862.0000370.

[102] B. Hwang, J.S. Tan, Green Building Project Management: Obstacles and Solutions for Sustainable Development, Sustain. Dev. 349 (2012) 335–349. doi:10.1002/sd.492.

[103] H. Li, S.T. Ng, M. Skitmore, Stakeholder impact analysis during post-occupancy evaluation of green buildings – A Chinese context, Build. Environ. 128 (2018) 89–95. doi:10.1016/j.buildenv.2017.11.014.

[104] R.J. Yang, P.X.W. Zou, Stakeholder-associated risks and their interactions in complex green building projects: A social network model, Build. Environ. 73 (2014) 208–222. doi:10.1016/j.buildenv.2013.12.014.

[105] R.J. Yang, P.X.W. Zou, J. Wang, Modelling stakeholder-associated risk networks in green building projects, Int. J. Proj. Manag. 34 (2016) 66–81. doi:10.1016/j.ijproman.2015.09.010.

[106] C.C. Menassa, B. Baer, A framework to assess the role of stakeholders in sustainable building retrofit decisions, Sustain. Cities Soc. 10 (2014) 207–221. doi:10.1016/j.scs.2013.09.002.

[107] S. Goulden, E. Erell, Y. Garb, D. Pearlmutter, Green building standards as socio-technical actors in municipal environmental policy, Build. Res. Inf. 45 (2017) 414–425. doi:10.1080/09613218.2015.1116844.

[108] W. Eisenstein, G. Fuertes, S. Kaam, K. Seigel, E. Arens, L. Mozingo, Climate co-benefits of green

building standards: water, waste and transportation, Build. Res. Inf. 45 (2017) 828–844. doi:10.1080/09613218.2016.1204519.

[109] M. Assad, O. Hosny, A. Elhakeem, S. El Haggar, Green building design in Egypt from cost and energy perspectives, Archit. Eng. Des. Manag. 11 (2015) 21–40. doi:10.1080/17452007.2013.775100.

[110] E. Bartlett, N. Howard, Informing the decision makers on the cost and value of green building, Build. Res. Inf. 28 (2000) 315–324. doi:10.1080/096132100418474.

[111] C.L. Cheng, Evaluating water conservation measures for Green Building in Taiwan, Build. Environ. 38 (2003) 369–379. doi:10.1016/S0360-1323(02)00062-8.

[112] M. Ribau Teixeira, F.P. Camacho, V.S. Sousa, R. Bergamasco, Green technologies for cyanobacteria and natural organic matter water treatment using natural based products, J. Clean. Prod. 162 (2017) 484–490. doi:10.1016/j.jclepro.2017.06.004.

[113] N. Bin Chang, B.J. Rivera, M.P. Wanielista, Optimal design for water conservation and energy savings using green roofs in a green building under mixed uncertainties, J. Clean. Prod. 19 (2011) 1180–1188. doi:10.1016/j.jclepro.2011.02.008.

[114] M. Alonso Monterde, V. Gómez Lozano, I. Guillén Guillamón, J. Higón Calvet, P.A. López-Jiménez, Sustainable building strategies on regional scale: Proposal for the Valencian region in Spain, Indoor Built Environ. 25 (2016) 1054–1064. doi:10.1177/1420326X16659327.

[115] K.S. Dewlaney, M. Hallowell, Prevention through design and construction safety management strategies for high performance sustainable building construction, Constr. Manag. Econ. 30 (2012) 165–177. doi:10.1080/01446193.2011.654232.

[116] L.F. Goldberg, Green Buildings : a Systemic Approach To Sustainable Products and Systems Integration, J. Green Build. 3 (2005) 57–66.

[117] P. Wu, Y. Song, W. Shou, H. Chi, H.Y. Chong, M. Sutrisna, A comprehensive analysis of the credits obtained by LEED 2009 certified green buildings, Renew. Sustain. Energy Rev. 68 (2017) 370–379. doi:10.1016/j.rser.2016.10.007.

[118] R. Shad, M. Khorrami, M. Ghaemi, Developing an Iranian green building assessment tool using decision making methods and geographical information system: Case study in Mashhad city, Renew. Sustain. Energy Rev. 67 (2017) 324–340. doi:10.1016/j.rser.2016.09.004.

[119] Y. Zou, Certifying green buildings in China : LEED vs . 3-star, J. Clean. Prod. 208 (2019) 880–888. doi:10.1016/j.jclepro.2018.10.204.

[120] S. Sharif, S.N. Kamaruzzaman, M. Pitt, Implementation Framework of Green Building for Government Building: Menara Kerja Raya, Malaysia, J. Des. Built Environ. 17 (2017) 27–36. https://ejournal.um.edu.my/index.php/jdbe/article/view/10190/7246.

[121] R.Y.J. Siew, Alternative framework for assessing sustainable building funds : Green Building Fund, Build. Res. Inf. 43 (2015) 160–169. doi:10.1080/09613218.2014.936170.

[122] M. Shan, B. Hwang, L. Zhu, A Global Review of Sustainable Construction Project Financing : Policies , Practices , and Research Efforts, Sustainability. 9 (2017) 1–17. doi:10.3390/su9122347.