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Review

A bibliometric review of research on sustainable construction, 1994–2018

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A B S T R A C T

This bibliometric review of research aimed to document and synthesize research trends in the domain of ‘sustainable construction’ (SCON) over the past 25 years. Through bibliographical analysis of 2,877 Scopus-indexed documents, the review found that this is very recent literature with over 80% of the relevant documents published since 2010. It is a global literature with significant contributions from both economically developed and developing societies. Citation analysis identified key authors and documents that have shaped the evolution of this literature. Author co-citation analysis, used to identify the intellectual structure of the SCON knowledge base, surfaced four ‘schools of thought’ or dominant lines of inquiry. In order of size and significance these were *Alternative Materials for Sustainable Construction*, *Sustainable Construction Management*, *Recycling and Waste Reduction*, and *Social Sustainability in Construction Management*. Results of keyword co-occurrence analysis reaffirmed these findings concerning the conceptual structure of the SCON knowledge base, including the conclusions that ‘social sustainability’ represents the ‘weakest’ dimension and ’alternative materials’ the leading edge of this sustainability literature.

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1. Introduction

Along with power generation and automobile usage, the construction industry represents one of the three largest contributors to greenhouse gas emissions that threaten the Earth's climate (IPCC, 2019). Acknowledgment of this impact on society has led the global construction industry to take increasingly aggressive steps aimed at embracing more sustainable practices (Kibert, 2007). Whereas in the past cost reduction, operational efficiency, quality and profitability were the key drivers in construction management, project owners and managers are increasingly concerned with the environmental and social impact of construction projects (Ortiz et al., 2009). This trend reflects Kibert's (1994) definition of "[sustainable] construction as the practice of creating and operating a healthy built environment based on resource efficiency and ecological principles" (p. 3).

The emergence of 'green construction' over the past 20 years has challenged developers and builders to adopt a 'sustainability mindset' towards the design and management of construction projects (Bon and Hutchinson, 2000; Cole, 1998; Seyfang, 2010). In practice, concerns for sustainability have implications for site selection, land use, design practices, materials selection and application, project management, and stakeholder engagement (Barlow and Jashapara, 1998). This has led to the emergence of a multidisciplinary knowledge base in green construction which reaches into architectural design, materials science, project management, real estate development, finance, purchasing, technology, and engineering (Zhao et al., 2019).

These observations concerning the emergence of green construction as a field of research and practice frame this bibliometric review of research. The goals of the review were to document and analyze trends in research on sustainable construction (SCON) over the past 25 years. This bibliometric review addressed the following research questions.

1. What are the volume, growth trajectory, and geographic distribution of scholarship on SCON?
2. Which scholars have emerged as thought leaders in the SCON literature?
3. What is the intellectual structure of the SCON knowledge base?
4. What topics in SCON research have received the greatest attention in the literature?

Our review employed systematic methods to identify 2,877 Scopus-indexed documents related to sustainable construction. Using bibliometric data analysis (Zupic and Čater, 2015), the authors analyzed information extracted from these documents in order to document and analyze key trends in the evolution of SCON research published between 1994 and the end of 2018. This quantitative review of research seeks not only to assess the current status of this literature, but also to establish empirical benchmarks that can be used in charting its progress in decades to come. Thus, future reviews will be able to document changes in the size, growth trajectory and geographic distribution of this literature, as well as shifts in it underlying intellectual structure and topical orientation.

2. Conceptual framework

One of the first authors to conceptualize 'sustainability' in construction was Kibert (1994), who asserted that the construction industry would need to move towards the use of 'sustainable practices' that conserved scarce resources and promoted a healthy environment. While this seems to be stating the obvious in 2019, 25 years ago this represented a landmark challenge for the construction industry. Kibert further asserted that the need to address natural resource scarcity and environmental concerns would require significant changes in every phase of construction projects. A reorientation of construction practices towards sustainability represented nothing less than a sea change for the construction industry which had been previously guided by a single-minded pursuit of economic ends (Bon and Hutchinson, 2000; Hill and Bowen, 1997).

During the 2000s, 'green construction' and 'green building' were coined as umbrella terms that connoted a shift towards environmentally friendly construction practices (Ali and Al Nsairat, 2009). The initiation of 'sustainable development goals' by the United Nations further raised awareness of a concomitant need for greater stakeholder engagement and attention to social responsibility in the construction industry (Myers, 2005). For example, in 2009, Lam and colleagues observed that, "New sustainability requirements and changing priorities in construction management have spurred the emerging green specifications to a faster pace of development" (Lam et al., 2010, p. 646). Consistent with Kibert (2016) and Ortiz et al. (2009), we conclude that the global construction industry has been confronted with a 'transformative challenge' within a relatively short period of time.

Early reviews of this literature tended to focus on new management methods that addressed the tension between economic and environmental goals embedded in sustainability. In one of the first systematic reviews conducted in this field, Horvath (2004) highlighted the environmental impact of different choices in construction materials used in infrastructure projects. Embedding his review in the emerging framework of 'lifecycle assessment' (LCA), Horvath linked the environmental impact of construction materials to decisions made in supply chain management.

Ortiz et al. (2009) reviewed subsequent developments in lifecycle assessment (LCA) which was increasingly becoming a keystone of sustainable construction practice. LCA sought to optimize the construction process from, "the extraction of raw materials to the final disposal of waste building materials" (Ortiz et al. p. 181). LCA represented both a conceptual framework for thinking about construction management, as well as a set of tools that could be used to inform decision-making in construction projects. Ortiz and colleagues concluded that, "LCA is fundamental to sustainability and improvement in building and construction" in order "not only to meet consumer demands for environmentally friendly products, but also to increase the productivity and competitiveness of the green construction markets (p. 181).

Robichaud and Anantatmula (2011) reviewed the 'greening of project management practices' used to achieve economic and environmental objectives. They asserted that even under pressure to achieve sustainability goals, project efficiency and profitability had to be maintained. Their review highlighted innovative approaches to project management that enabled companies to meet higher environmental standards within existing cost constraints.

Zuo and Zhao (2014) conducted a critical review of research on 'green building'. Their review identified themes that had emerged within this literature, including the "definition and scope of green building; quantification of benefits of green buildings compared to conventional buildings; and various approaches to achieve green buildings" (Zuo and Zhao, 2014, p. 271). Their review further highlighted an imbalance between environmental and social sustainability in the sustainable construction literature, with far fewer documents published on the latter theme.

More recently, scholars have employed bibliometric methods which are more directly comparable to the approach used in the current review (e.g., Santos et al., 2017; Zhao et al., 2019) . Santos and colleagues (2017) used bibliometric methods to review research on building information modeling (BIM), a methodology that leveraged information technology in response to demands for more sustainable construction. The review documented evidence of growing worldwide application of BIM from 2005 to 2015. Nonetheless, they also noted a relative paucity of “academic research” on the extent to which BIM has helped construction projects achieve sustainability goals.

Zhao et al. (2019) followed up on the earlier review by Zuo and Zhao (2014) with an updated bibliometric review of ‘green building research’. This review used bibliometric methods to identify topical clusters as well as ‘hot topics’ concentrated in recent years. It was interesting to note that this review again identified social sustainability as a continuing gap in this literature.

In contrast to several of the above reviews, the current review did not focus on a specific sustainable construction method (e.g., LCA, BIM). Rather we adopted a broad perspective on ‘sustainable construction’. While the bibliometric method used in this review most closely resembles the methods used by Santos et al. (2017) and Zhao et al. (2019), our review was designed both to extend and fill in gaps in trends reported in these prior reviews.

3. Method

This section describes the procedures used in the identification of studies for the review as well as methods of data analysis.

3.1. Identification of sources

The Scopus index was selected as the data repository from which to search for and extract documents. Empirical comparison have found that Scopus offers more comprehensive coverage of sources than the Web of Science for fields of study outside of medicine and the physical sciences (Hallinger and Kovačević, 2019; Mongeon and Paul-Hus, 2016). The review adopted a broad scope in terms of document types with the inclusion of journal articles, books, book chapters, and conference papers. No start date was specified for the Scopus search, thereby allowing the search engine to identify the earliest papers in the literature.

The review adopted PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for conducting systematic reviews of research. The search string “sustainable construction” OR “green construction” was entered into the Scopus search engine. This initial search yielded 3,339 documents (see Fig. 1). After Scopus subject filters were applied, the database was reduced to 2,913 documents. Additional documents were excluded based document type. For example, trade publications, short surveys, notes, reports and errata were eliminated at this stage. After scanning the abstracts of all documents in the list further exclusions were made based on topical relevance. After the screening of documents was complete, the final database included 2,877 documents on sustainable construction.

3.2. Data analysis

The ‘data’ analyzed for this review consisted of bibliographic information describing features of the 2,877 Scopus-indexed documents. These ‘meta-data’ included the author names, titles, publication dates, and author affiliations of the documents, as well as copious citation information. Descriptive statistics were used to conduct trend analyses related to the growth and geography of the SCON literature.

Bibliometric analyses conducted in VOSviewer software (Van Eck and Waltman, 2014) were employed to synthesize patterns of knowledge production in the SCON literature. Author co-citation analysis (White and McCain, 1998) was employed in order to analyze the ‘intellectual structure’, or research traditions, that have evolved in this knowledge base. Co-citation analysis calculates the number of times that two authors have been cited together in the reference lists of documents contained in the review database (Zupic and Čater, 2015). Because co-citation analysis scanned the reference lists rather than Scopus, its results reflect patterns of scholarly influence in the ‘broader literature’. Thus, to some extent, co-citation overcomes a limitation of ‘traditional citation analysis’ which is limited to the analysis of documents from a particular document repository (e.g., Scopus, Web of Science).

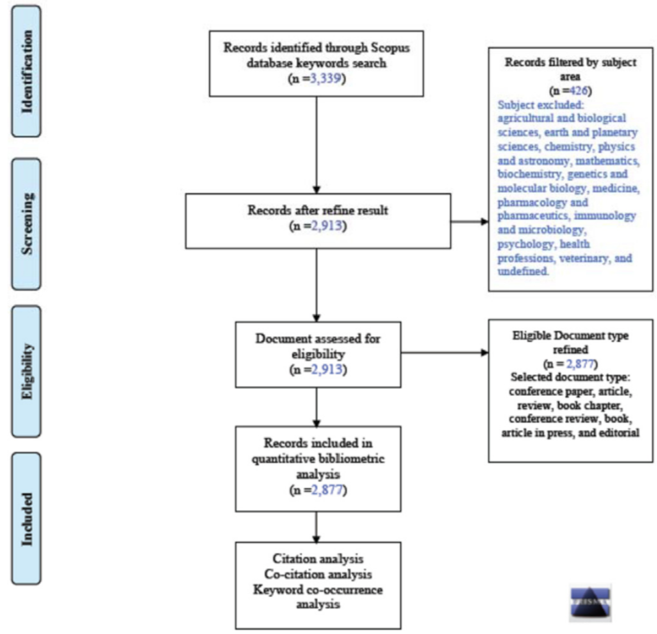

Fig. 1. PRISMA flow chart of procedures used in the identification of sources for the SCON review

Co-citation analysis has also been used as the basis for the ‘visualization of similarities’ (VOS), a powerful approach to network mapping (Van Eck and Waltman, 2014). Co-citation analysis assumes that when two scholars are frequently ‘cited together’ by other authors, they tend to share a similarity in theoretical perspective (White and McCain, 1998). Author co-citation analysis in VOSviewer transforms patterns of author co-citation into a social network map that visualizes similarities among the authors in a particular literature (Van Eck and Waltman, 2014). Author co-citation maps have been used to map the intellectual structure of sustainability in different domains, including higher education (Hallinger and Chatpinyakoop, 2019), human resource management (Kainzbauer and Rungruang, 2019), and green building (Zhao et al., 2019).

Our final research question was addressed through the application of keyword co-occurrence analysis (co-word analysis) in VOSviewer. Van Eck and Waltman (2014) stated that, “The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract, or keyword list [of documents in the review database]" (p. 289). In a similar fashion as co-citation analysis, co-word analysis has been used to visualize similarities among frequently co-occurring keywords (i.e., topics) in a literature (Zupic and Čater, 2015, p. 435). In this review, temporal co-word analysis was used to identify topics that have featured in the most recent literature.

4. Results

This section describes the results of the bibliometric analysis of the 2,877 SCON documents published from 1994 through 2018.

4.1. Analysis of descriptive trends in the SCON knowledge base

The 2,877 Scopus-indexed documents published over the past 25 years represent a large and rapidly growing knowledge base on sustainable construction. Interest in 'sustainability' in the construction industry emerged slowly during the 1990s (25 documents), but picked up pace with the publication of 523 documents during the 2000s. Fully 82% of this literature was published between 2010 and 2018 leading to the conclusion that this is a rapidly emerging literature (see Fig. 2).

The 2,877 documents were distributed across 98 countries, affirming worldwide interest in sustainable construction (see Fig. 3). A majority of publications were authored in Anglo-American-European societies. At the same time, however, China has become increasingly influential in this field establishing a strong presence especially in the environmental domain (e.g., Li et al., 2018; Qi et al., 2010). More broadly, the strength of Asian societies among the leading producers of SCON research contrasts with other fields of sustainability science (see Fig. 3).

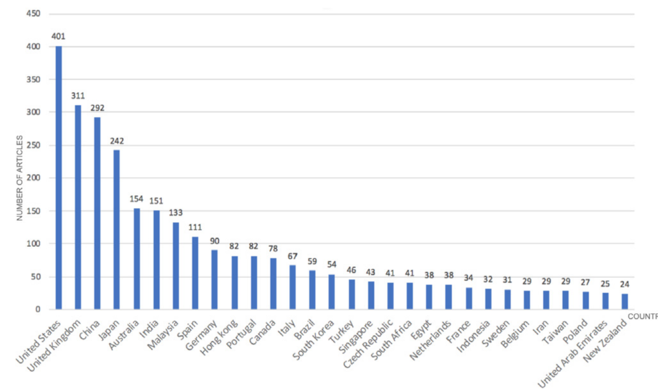

Fig. 3. Global distribution of SCON publications from counties with more than 20 publications, 1994–2019 (n = 2,877).

4.2. Key authors and the intellectual structure of the SCON knowledge base

Our second and third research questions sought to reveal key authors as well as the emerging 'intellectual structure' of the SCON knowledge base. Zupic and Čater (2015) referred to intellectual structure as the schools of thought that represent the key research traditions within a knowledge base. As noted above, VOSviewer reveals these schools of thought through the visualization of author relationships based on patterns of co-citation.

An author co-citation map was created in VOSviewer displaying the 126 authors who had met a threshold of at least 45 co-citations (see Fig. 4). The author co-citation map revealed four distinct but inter-related schools of thought in sustainable construction management. On the map, each school of thought is comprised of a cluster of frequently co-cited scholars. Size of a node signifies the author's relative level of co-citation by other scholars. Thus, co-citation analysis identified Poon, (398 co-citations), Shen (341), Kibert (300), and Tam (236) as the most frequently cited scholars in this literature.

As suggested above, co-citation analysis also offers insight into relationships among authors. When two authors are connected by a 'link', it is an indication that they have been co-cited by a third scholar. Thus, the large size of the node and dense links emanating from Poon on the map indicate that he has not only accumulated many co-citations (i.e., large size of the node), but also that he has been co-cited with a large number of other scholars (i.e., numerous links). These factors, along with his central location on the map, position Poon as the key 'boundary spanning scholar' in this literature. According to White and McCain (1998), boundary spanning scholars play a key role in the development of a literature by integrating the different conceptual streams or schools of thought that cohere into a literature.

The distance between authors, as well as between schools of

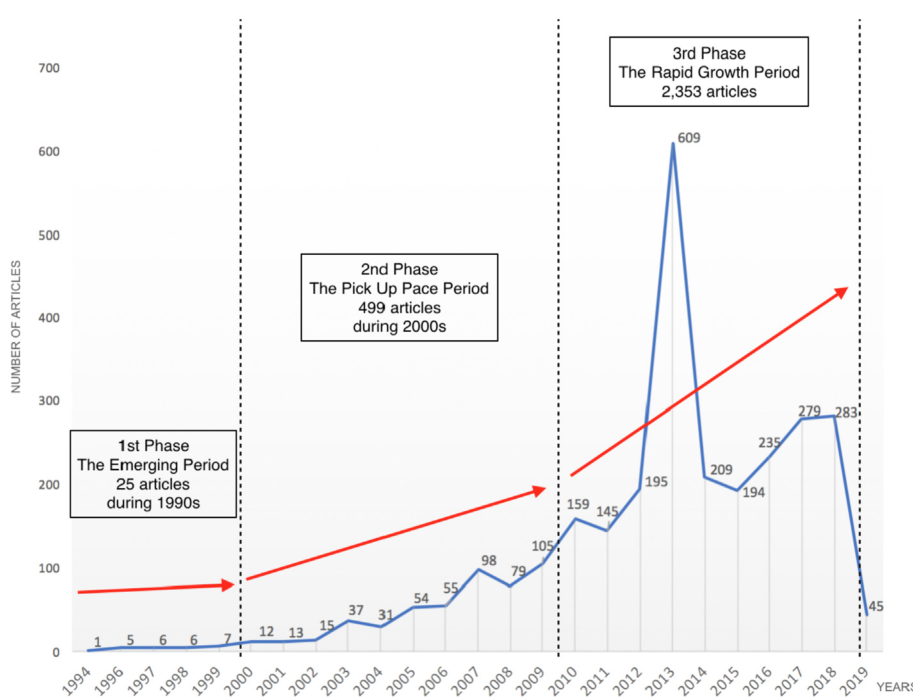

Fig. 2. The growth trajectory of SCON publications, 1994–2019 (n = 2877).

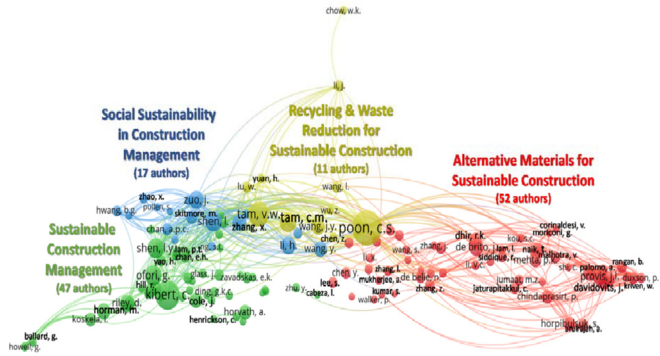

Fig. 4. Schools of Thought in the SCON literature based on author co-citation analysis (61,424 in the author network; threshold of 45 co-citations with display of 127 authors in four clusters)
Note: Size of node refers to frequency of co-citations in reference lists of the review documents; proximity refers to frequency with which two authors have been co-cited; color refers to the clustering of authors based on patterns of co-citation in the review documents.

thought, offers a further indication of the degree of intellectual affinity or connection. Thus, for example, note the close proximity and high density of links between the Materials Use and Waste Reduction schools. This suggests more frequent co-citation among their composite authors, and by extension, closer intellectual affinity. In contrast, these schools of thought are less connected to the Social Sustainability School.

The green cluster represents a school of thought termed *Sustainable Construction Management*. Scholars in this school have been concerned with defining the field (Kibert, 2007) and elaborating management practices that contribute to sustainable construction (Kubba, 2012). Key authors in this school include Kibert (300 co-citations), Shen (341), Ofori (175), Riley (142), Horman (128), Horvath (112), Hill (109), and Pearce (101). These scholars have also led the way in identifying key innovations (Hill and Bowen, 1997) and emergent practices (Qi et al., 2010) in managing for construction sustainability. They have also made practical contributions by identifying and testing new ways of measuring the use of sustainable practices in construction projects (Chen et al., 2010; Cole, 1998).

Scholars in this school have also investigated the environmental impact of different construction practices (Hendrickson and Horvath, 2000). They have, for example, documented the development and validation of 'life-cycle assessment' (LCA) as a signature planning tool used to promote sustainable construction (Pitt et al., 2009). Application of life-cycle assessment addresses a crucial concern because the environmental impact of any construction project extends far beyond on-site activities (Zabalza et al., 2013). It begins with sourcing of raw materials, continues to waste management during construction, to operation and maintenance during the building's use, and finally to demolition of waste at the end of a building's useful life (Kovacic et al., 2016).

LCA has developed into a widely-used tool for planning construction projects from "cradle to grave" (Peris Mora, 2007). Indeed, over the past 20 years LCA has gained international acceptance as a tool for improving environmental performance throughout the supply chain in the construction industry (Sharrard et al., 2008). Recently, the research trend in LCA has extended into building optimization (Kovacic et al., 2016), construction materials (Silvestre et al., 2016), energy efficiency (Sesana and Salvalai, 2013), and building design strategies (Wong and Zhou, 2015).

The blue cluster in Fig. 4 represents the *Social Sustainability in Construction Management* school of thought. Scholars in this school have studied the social impact of construction and real estate development projects. The intermingling of scholars in this school with the green and yellow schools suggests overlapping concerns with management methods and practices (e.g., project mnagement, LCA). Leading scholars in this school include Zuo (151 co-citations), Li (149), Zhang (140), Wang (124), and Skitmore (98). Scholars in this school have sought to understand sustainable construction from the perspective of different stakeholders including project owners (Gan et al., 2015), project partners (Barlow and Jashapara, 1998), contractors (Tan et al., 2011), suppliers (Chen et al., 2008), and communities (Li et al., 2018).

This school of thought is most closely associated with the emphasis on 'corporate social responsibility' (CSR) in the broader sustainability literature (Myers, 2005). The CSR emphasis creates an expectation that construction project owners and managers will execute construction projects that deliver a positive social impact to society (Xia et al., 2018). Managers of construction enterprises are increasingly pressed to adopt 'good governance' practices by governments, non-governmental organizations, and the public (Myers, 2005). A growing international acceptance of CSR in construction has resulted in the formulation and adoption of standards that are reshaping industry practices worldwide (Zhao et al., 2012). For example, the Global Reporting Initiative (GRI) and the International Organization for Standardization (ISO) now offer relevant operational definitions of CSR and associated indicators (e.g., ISO 26000 and ISO 14001 series). In sum, CSR in sustainable construction has emerged as a recent trend driven by the need for more responsible business operations (Moratis and Cochius, 2011).

The yellow cluster is associated with *Recycling and Waste Reduction for Sustainable Construction*. Although slightly smaller than the *Social Sustainability in Construction* school, it actually contains more influential scholars and higher citation impact. The leading scholars in this school are located in Hong Kong and mainland China: Poon (398 co-citations), V.W. Tam (236), C.M. Tam (174), and J.Y. Wang (124). Scholars in this school have sought to understand how construction design (Wang et al., 2015) and waste management practices (Jaillon et al., 2009) can reduce unnecessary waste in construction projects.

Influenced by life cycle assessment, scholars in this school have conceptualized waste management in terms of both materials/resource usage and waste (Yeheyis et al., 2013). Innovative practices associated with waste management seek to reduce unnecessary use of natural resources (Osmani, 2012), lower energy consumption (Mansour and Ali, 2015), and place less burden on landfills (Jaillon and Poon, 2010) while also reducing costs. As waste is a major cause of environmental pollution, waste reduction can mitigate environmental harm and reduce stress on natural resources (Poon et al., 2004).

Another recent trend in waste management in sustainable construction is geared towards the adoption of technological innovations (Geissdoerfer et al., 2017). These include, for example, efforts to transform 'waste' to energy (Ajayi et al., 2017) and replace raw materials with recovered waste materials (Muñoz Velasco et al., 2014; Rajczyk, 2014). This supports the broader sustainability trend of achieving a 'circular economy' throughout the construction supply chain.

The largest (red) of the four schools of thought in terms of number of scholars focuses on *Alternative Materials for Sustainable Construction*. Leading scholars include Debrito (139 co-citations), Provis (139), Dhir (118), Palomo (112), van Deventer (108), Mehta (108), Horpibulsuk (107), Davidovits (105), and Chindaprasirt (100). Scholars in this school have examined uses of innovative (Velasco et al., 2014), recycled (Manzi et al., 2013), and sustainably sourced materials in construction (Silvestre et al., 2016).

Concrete has become recognized as one of the most environmentally harmful materials used in construction due to the high CO2 emissions that result at different phases in the building life cycle (González and García Navarro, 2006). Therefore, in order to reduce CO2 emissions and mitigate environmental impact there is a trend to replace traditional concrete with more environmentally friendly alternatives (Evangelista and de Brito, 2007). This research has studied the cost, durability, and environmental impact of alternative construction materials (González and García Navarro, 2006) such as recycled aggregate concrete (Manzi et al., 2013), geopolymer foam (Zhang et al., 2014), fly ash (Suksiripattanapong et al., 2015), recycled plastic (Mansour and Ali, 2015), and agricultural solid waste (Raut et al., 2011).

4.3. Topical trends in the SCON knowledge base

Topical analysis was employed to extend the findings from co-citation analysis. A co-word map was generated in VOSviewer using a threshold of 50 keyword co-occurrences (see Fig. 5). We synthesized the keywords comprising each cluster in order to surface themes in the literature.

The map in Fig. 5 reveals three themes representing *Sustainable Construction Methods, Sustainable Construction Materials*, and *Recycling and Waste Reduction*. This map reprises three of the schools of thought obtained through author co-citation analysis (see Fig. 4). Only the social sustainability theme is missing from the co-word map.

The final analysis applied a temporal overlay to the co-word map shown above in Fig. 5 (see Fig. 6). The temporal overlay links keywords to the date of publication of their documents. Temporal co-word analysis reveals the time period when particular topics were at the height of their popularity (Zupic and Čater, 2015). Thus, analysis of the topics by color/shade enables us to trace the evolution of the SCON literature over the past 25 years. Darker nodes represent topics that were popular earlier in this literature and lighter shades those that have featured in the recent literature.

The temporal co-word map suggests that the current literature is focused on three topical themes (see Fig. 6). First and foremost, the leading edge of this literature lies in exploring innovations in the use of alternative construction materials as a means of enhancing sustainability (Corinaldesi and Moriconi, 2009). The dominance of this theme is clearly established by the number of yellow/lighter shade nodes on the right side of the map.

The other ‘hot topics’ surfaced by the temporal co-word map are architectural design (126 co-occurrences) and greenhouse gases (72 co-occurrences). ‘Architectural design’ (Kubba, 2012) is increasingly linked to ‘intelligent buildings’ (Ghaffarianhoseini and Berardi, 2016) as well as to ‘green construction’ (Kibert, 2016). For example, as noted earlier, BIM has emerged as a means of enhancing the integration of design and construction processes (Wong and Fan, 2013), with positive effects on time, cost, quality and environmental assessment (Inyim et al., 2014). Smart technology and cloud-based information management systems (Rawai et al., 2013) can aid collaboration in the design-build-operation process, thereby enabling projects to achieve higher levels of building optimization, environmental performance and economic feasibility (Inyim et al., 2014). Data-driven approaches and

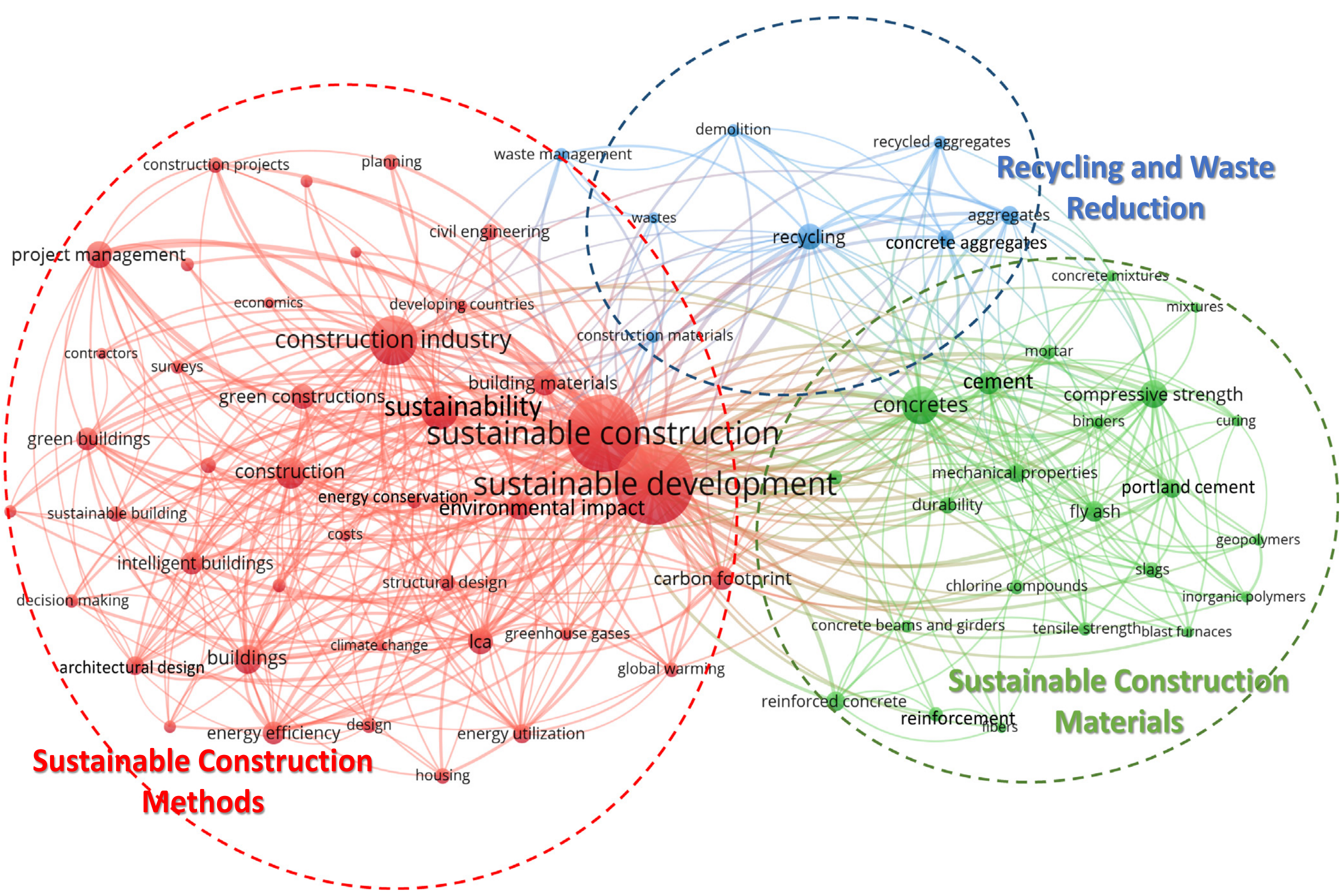

Fig. 5. The main foci of SCON studies based on keyword co-occurrence analysis (Keyword threshold = 50; display 72 keywords)
Note: Size of node refers to frequency of occurrence; proximity of nodes is based on patterns of their co-occurrence in the review documents; clustering by color is based on patterns of co-occurrence among multiple keywords in the review documents.

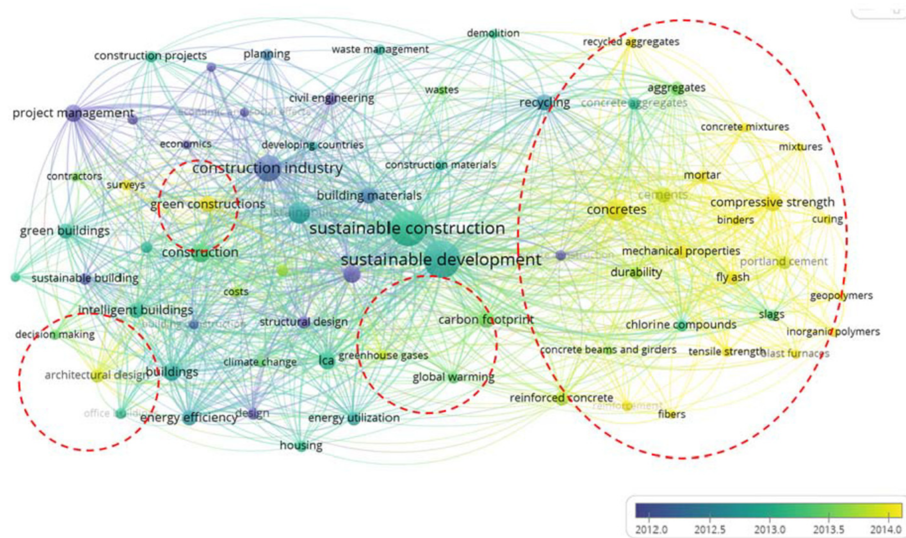

Fig. 6. Temporal overlay on keyword co-occurrence map (keyword threshold = 50; display 72 keywords)
Note: Size of node refers to frequency of occurrence; proximity of nodes is based on patterns of their co-occurrence in the review documents; color refers to the relative recency with which a topic has occurred in the review documents.

innovations in ICT now allow better predictive modeling (Löwe, Albrecht, Fischer, & Wittstock, 2010) and decision making (Chokor and El Asmar, 2016) aimed at creating sustainable built environments.

The keyword 'greenhouse gases' (e.g. (Akan et al., 2017), was linked to 'carbon footprint' (Seyfang, 2010), 'global warming' (Zabalza et al., 2013), 'life-cycle assessment' (Sesana and Salvalai, 2013), and 'energy utilization' (Kua, 2015). Thus, innovations such as energy performance building (EPBD) and zero and nearly zero building (ZEB and nZEB) focus on reducing energy needs and uses. The energy use concept leads to a paradigm shift in the way built-environments are designed, built, and operated (Sesana and Salvalai, 2013). Energy saving in building and construction promote lower impact on global warming by decreasing greenhouse gas emissions (Zabalza et al., 2013). This has resulted in the development of design methodologies, assessment procedures, LCA tools and carbon footprint calculators for environmental impact prediction and feasibility assessment (Ortiz et al., 2010).

5. Discussion

Employing bibliometric analysis, this research review documented the emergence of literature on sustainable construction management over the past 25 years. In addition, the review surfaced important themes that are defining the meaning and range of sustainable construction practices. In this section, we highlight limitations and interpret findings from the review.

5.1. Limitations of the review

Key limitations of this review are related to the topical scope and source of documents. This review focused on the topic of 'sustainable construction'. At times, the breadth of this topic led to ambiguity when it came to the application of inclusion/exclusion criteria during the search phase of the review.

A second limitation arises from our reliance on Scopus index as the source of documents. While Scopus offers more comprehensive coverage than the Web of Science (Mongeon and Paul-Hus, 2016), it offers somewhat less complete coverage of books, and conference papers than journal articles. The use of author co-citation analysis mitigated this limitations by capturing additional relevant literature referenced by documents in our review database.

5.2. Interpretation of the findings

This bibliometric review identified a substantial knowledge base on sustainable construction consisting of 2,877 Scopus-indexed documents published between 1994 and 2018. Our results documented a relatively modest pattern of growth from 1994 to 2009, followed by an explosion of research published in subsequent years. Indeed, fully 82% of the documents in our database were published since 2010. This affirms the conclusion that this is a dynamic, rapidly changing knowledge base capable of yielding potentially important findings over a relatively period of time.

Interest in sustainable construction is a global phenomenon, with significant bodies of research emerging not only from Anglo-American-European countries, but also from other regions of the world. Indeed, the global breadth and depth of research on 'sustainability' appears to be far greater in construction than in other sustainability management domains (Hallinger and Chatpinyakoop, 2019; Kainzbauer and Rungruang, 2019). This trend towards the development of a global literature on sustainable construction adds additional clarity and support for findings previously reported by Santos et al. (2017), and Zhao et al. (2012). Thus, we assert that these data confirm the universality, urgency and potency of forces that are driving 'sustainability' into every facet of the global construction industry.

A unique contribution of science mapping lies in the ability to visualize the conceptual structure of scientific disciplines (Zupic and Čater, 2015). Taken together, co-word and author co-citation analyses surfaced three conceptual themes in the sustainable construction literature: *Sustainable Construction Management, Recycling and Waste Reduction,* and *Alternative Materials for Sustainable Construction*. Identification of these conceptual pillars of the SCON knowledge base reaffirm the dual emphasis in this literature on economic and environmental concerns highlighted in prior bibliometric reviews of this literature (e.g., Zhao et al., 2019; Zuo and Zhao, 2014). While our respective findings overlap in several respects, the results of this review more clearly highlight the themes of 'waste reduction' and 'alternative materials for construction' as conceptual pillars in the SCON knowledge base.

Consistent with other recent reviews (e.g., Zhao et al., 2019; Zuo and Zhao, 2014), our co-author and co-word analyses found that 'social sustainability' remains a secondary theme in the SCON knowledge base. For example, while Social Sustainability in Construction Management did surface in the author co-citation analysis, it was the 'weakest' of the four identified schools of thought. Moreover, this theme was missing entirely from the co-word map. This is especially significant because co-word analysis is based on actual context extracted from the review documents sbeased on actual content extracted from (Zupic and Čater, 2015). This suggests that the focus on CSR (Myers, 2005) stakeholder engagement (Barlow and Jashapara, 1998), affordable, socially responsible housing (Zhao et al., 2019), and worker diversity and equity (Hendiani and Bagherpour, 2019) continue to represent secondary considerations in sustainable construction research and practice (Jiang and Wong, 2016). This finding is supported by other literature which has identified a lack of standards for guiding and measuring social sustainability in the construction industry (Zhao et al., 2019). Thus, we conclude that the 'construction sustainability mindset' remains dominated by the 'hard' side construction (e.g., materials, waste, management, natural resource usage, energy).

The dominant theme surfaced by co-word analysis concerned investigations of innovative and alternative materials for sustainable construction (Madurwar et al., 2013). These include the increased use of different types of aggregates in cement, concrete and asphalt, as well as geopolymers, fly ash, industrial and agricultural solid waste, plastic and foam, and concrete recycled from demolished buildings (Muñoz Velasco et al., 2014). In addition to identifying alternative materials to reduce the unsustainable use of natural resources, this research has also examined the mechanical properties and durability of these alternatives (Evangelista and de Brito, 2007). This finding traces back to initial findings reported by Horvath (2004), but which has received somewhat less emphasis in recent reviews of green building research.

This emerging field also encompasses efforts to identify 'rapidly renewable' and 'low-impact' construction materials such as bamboo (Mahdavi et al., 2012), sugarcane (Kazmi et al., 2016), rice husks (Kazmi et al., 2016), and rammed earth (Kariyawasam and Jayasinghe, 2016) as selective replacements for concrete and steel. Indeed, temporal co-word analysis identified this 'engineering and materials science' dimension of sustainable construction as the cutting edge of the SCON literature (Provis et al., 2015). Other topics at the research front of this knowledge base include architectural design and construction practices aimed at more efficient energy utilization and reduction of greenhouse gasses in the construction supply chain. This finding reaffirms results reported in other recent reviews of research on sustainability in the construction industry (Zhao et al., 2019; Zuo and Zhao, 2014).

5.3. Conclusion

In conclusion, this review has documented the emergence and accelerating growth of a remarkably robust, global literature on sustainable construction. Whether analyzed in terms of document volume, conceptual coherence, citation impact, or breadth and depth of global penetration, this literature compares favorably with sustainability literatures in other management domains (e.g., Hallinger and Chatpinyakoop, 2019; Kainzbauer and Rungruang, 2019). Moreover, the growth trajectory of this literature suggests that it will more than double in size over the next decade. These data suggest that the literature on sustainable construction represents holds one of the keys to worldwide sustainable development in future years.

Submission declaration

The authors declare this manuscript has not been published nor has it been submitted in any form.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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