Bibliometric analysis of the construction education research from 1982 to 2017

Linzi Zheng[1], Ke Chen[2], Weisheng Lu[3]

Abstract

Research into construction education (CE) has garnered increasing attention over the last few decades and a great number of CE studies have been published. However, few studies have mapped the global geography and perspective of that research. This paper presents the first bibliometric analysis of CE studies published between 1982 and 2017 in order to chart the academic development and identify of various research directions within the field. Focusing on development trends, knowledge body structure, major journals, and collaboration networks and applying quantitative evaluation results allowed instructive findings and implications concerning the possible deficiencies in CE research to be derived. The analysis of keyword trends indicates that new concepts like building information modeling and sustainability have recently become hot topics in CE research. The most influential articles, journals, authors, and countries/regions were also identified. The findings also imply that current CE research shows a bias toward technology utilization in education and the existence of considerable isolation between formed groups, such as collaboration networks. This study contributes to CE literature by providing useful information of its status quo and suggesting potential directions for future CE research.

Keywords: construction education; bibliometric analysis; systematic review; research direction

[1] Postdoctoral Fellow, Department of Economics, Jinan University, Guangzhou, China, Email: h1099026@connect.hku.hk;

[2] Postdoctoral Fellow, corresponding author, Knowles Building, Department of Real Estate and Construction, The University of Hong Kong, Hong Kong, Email: leochen@connect.hku.hk;

[3] Associate Professor, Knowles Building, Department of Real Estate and Construction, The University of Hong Kong, Hong Kong, Email: wilsonlu@hku.hk;

Introduction

Over the past decades, the world's construction markets have ebbed and flowed, while a global emphasis on more sustainable and innovative approaches in project delivery have risen continually (Robichaud and Anantatmula, 2010; Becerik-Gerber et al., 2011). Education is key to cultivating a more skilled and conscious labor force and therefore also to fostering emerging development practices within the construction industry (Smith et al., 2018). Construction educators wish to better understand various pedagogical methods, resulting in a burst of recent research on construction education (CE), with a general aim of improving learning outcomes of both students and industrial practitioners.

The wealth of CE literature deserves a pause in order to grant a retrospection of the accumulated publications. A systematic review of the literature can help advance the existing knowledge, develop theories, recognize connections and networks within the various research, and uncover new and supplementary directions for future research (Webster and Watson 2002; Abotaleb and El-adaway 2018). Several reviews of the CE literature have been carried out, including Murray and Cotgrave (2007), Abdirad and Dossick (2016), and Wang et al. (2018). Although insightful and noteworthy, these evaluations mostly relied on a manual review method and produced qualitative, sometimes subjective findings. Moreover, they were often in the service of particular goals, e.g., to make judgments concerning different pedagogical techniques.

This paper aims to remedy the deficit of prior reviews and achieve a quantitative overview of CE research. It does so by applying bibliometric techniques to a large dataset of CE studies published between 1982 and 2017. Indispensable instruments for measuring scientific progress (van Raan 2005), bibliometric techniques offer important quantitative perspectives to assess the development of research in a specific area. This paper seeks to chart the academic development and identify research directions of CE research by realizing four objectives: (1) to reveal development trends of CE publications, (2) to characterize the structure of CE knowledge, (3) to quantitatively evaluate the academic influence of journals that publish CE studies, and (4) to uncover scientific collaboration networks between authors and countries/regions within the CE research community. This paper not only provides an effective reference basis to identify neglected or under-researched CE topics, but also suggests new directions to move CE research forward.

The remainder of this paper comprises five sections. The subsequent section briefly describes the background of CE and CE research. Then, the research methods, including the analytical procedure, methods of data collection, and bibliometric techniques and tools are introduced. Next, the results and findings are presented. The following section discusses the derived findings, based on which future research directions are also suggested. Conclusions are drawn in the last section.

Background

CE focuses on the lifecycle of a constructed facility (Oglesby, 1990). It began modestly in the 1920s as part of early civil engineering degree programs (Abudayyeh et al., 2000). After World War II, the gradual need for more specifications in conception, design, procurement, construction, operation, and maintenance led to the formation of construction specialty programs (Abudayyeh et al., 2000). Nowadays, many educational institutions offer construction specialty programs to teach students about engineering, design, management, and technologies (Becerik-Gerber et al., 2011). Many firms also provide training and continuing professional development to employers in order to improve their expertise. As more and more importance was placed on quality education in construction specialties, CE literature has built, helping to improve the learning outcomes of students and industrial practitioners.

The understanding that CE cannot escape the dynamics of labor demand and that the establishment of the labor market depends on development tendencies in the construction industry has also partially inspired rising interest in CE research. In recent years, two development tendencies in the construction industry have been especially remarkable. First, most countries or regions have experienced lengthy and sizable construction booms sometime between now and the late 1980s (Ball et al., 2012). Second, a global interest in more sustainable and innovative approaches to construction has emerged due to the escalating cost of materials and energies and the importance of environmental protection (Robichaud and Anantatmula, 2010; Becerik-Gerber et al., 2011). As a result, construction labor demand has not only amplified, but necessitated that workers be able and willing to embrace new concepts and technologies (Becerik-Gerber et al., 2011; Clevenger et al., 2017). These tendencies in construction and the resultant labor requirements have raised active challenges to CE and compelled CE research to grow.

Existing CE studies have covered a great variety of topics. For example, Chinowsky et al. (2006) studied the pros and cons of different pedagogical methods. El-adaway et al. (2015) developed skillset centered curriculum principles based on insights from problem-based learning and service learning pedagogies. Scores of researchers have focused on the use of advanced technologies, e.g., virtual reality and game-based simulation, as teaching tools (e.g., Teizer et al., 2013; Park et al., 2016). In addition to studies on pedagogies and teaching approaches, some researchers made judgments on the economic impacts of investing in education (e.g., Glover et al., 1999). Even these studies only form a small portion of the CE literature. They indicate that CE research builds on the contributions of various disciplines and research methods typically used in economics, sociology, and phycology (Becerik-Gerber et al., 2011). The field's large body of existing research warrants a rigorous bibliometric analysis in order to examine its existing intellectual core and pinpoint deficiencies and omissions.

Research Methods

The primary method used in this paper is bibliometric analysis. Bibliometrics allows the quantitative and holistic probing of the literature, possibly unattainable through the manual review method alone (Ball and Tunger 2006). Following Hosseini et al. (2018), a four-step analytical procedure was adopted, including *data collection*, *data processing using bibliometric techniques*, *analysis and visualization*, and *communication of findings*. This section introduces the first two steps, while the following section covers the latter two.

Data Collection

This paper selected the database, *Scopus*, to download the analyzed bibliographic records. *Scopus* is recognized as one of the largest abstract and citation databases of peer-reviewed journals, books, and conference proceedings and offers faster indexing processing than other key scholarly databases, such as Web of Science and Google Scholar (Meho and Rogers, 2008). *Scopus* also allows a combination of constraints to streamline the document search.

Five terms were entered to search *Scopus*, i.e., "construction education", "construction engineer* education", "construction manag* education", "construction engineer* teach*", and "construction manag* teach*". In addition to the search terms, rules for an advanced search were also set, i.e., the timeframe was "before 2018"; the document type was "Article"; the

source type was "Journals"; and the language was "English". Based on these search terms and rules, the query string used for searching Scopus was: *(TITLE-ABS-KEY ("construction education") OR TITLE-ABS-KEY ("construction engineer*" OR "construction manag*" AND " teach* ")) AND DOCTYPE (ar) AND PUBYEAR < 2018 AND (LIMIT-TO (SRCTYPE , "j ")) AND (LIMIT-TO (LANGUAGE , "English ")*, where " * " denoted a fuzzy search.

Conducted on March 6, 2018, the database search initially collected 272 records. Some of these records were published in irrelevant disciplines, such as chemistry or agricultural and biological sciences. To filter these records, manual screening was performed. Finally, 232 articles were selected covering a period of thirty-six years, i.e. the oldest paper retrieved printed in 1982. Each bibliographic record contained the metadata of the article, including title, authors and their affiliations, abstract, keywords, title of journal, year of publication, volume and page numbers, number of citations, list of references, and DOI.

Bibliometric Techniques and Tools

Four bibliometric techniques were applied to analyze the downloaded dataset: (1) keyword co-occurrence analysis, which maps keywords in terms of their co-occurrences in documents; (2) bibliographic coupling analysis, which produces the co-citation patterns between documents; (3) direct citation analysis, which focuses on citations between journals; and (4) co-authorship analysis, which uncovers the collaboration patterns between authors and between countries/regions. As summarized in Table 1, the first two techniques are used to depict the knowledge body in CE; the third technique, to identify the prominence of journals for CE publications; the fourth technique, to discover the collaboration network in the CE research community.

Regarding the tools for performing these techniques, VOSviewer is commonly made use of to construct networks of publications, journals, researchers, organization, countries, and keywords, and visualize such networks in detail (van Eck and Waltman, 2014). While Pajek is a widely adopted network analysis tool that can help analyze large networks, including finding clusters within a network, extracting vertices of a cluster, and depicting relations among clusters. Thus, VOSviewer and Pajek were considered suitable tools for this paper (see Table 1).

<Please insert Table 1 here>

Analytical Results and Findings

Based on the highlighted research methods, the authors present below the results concerning the development trends of CE publications (i.e., finding I), the structure of the body of CE knowledge (findings II-VII), the prominent journals for CE studies (i.e., findings VIII-XI), and scientific collaboration within the CE community (i.e., findings XII-XV).

Development Trends of CE Publications

Fig. 1 shows the number of CE studies published over time. The first CE paper was published in 1982 by Oglesby in *Journal of the Construction Division*. From Fig. 1, it is evident that the number of publications fluctuated widely until roughly 2000, after which, a steady increase in the number of publications, as presented by the dashed curve in Fig. 1, occurs. This increase can also be measured by the relative growth rate (RGR), a widely-used indicator proposed by Mahapatra (1985) for assessing changes in the number of publications over a certain period (Krishnamoorthy et al., 2009). RGR is calculated as $\frac{\ln P_2 - \ln P_1}{t_2 - t_1}$, where $\ln P_2$ is the natural logarithm of the number of publications at time t_2, $\ln P_1$ is the natural logarithm of the number of publications at time t_1. As summarized in Table 2, the RGRs remained positive between 2000 and 2017, reflecting the growing CE publications each year during that period. More specifically, the RGRs were high between 2000 and 2003, then wavered downward thereafter, and relatively steadied from 2014 to 2017.

The increase in the annual CE publications since 2000 could either reflect the growing trend in CE studies, i.e., the real change, or might be a result of *Scopus* being more comprehensive in the 2000s than the period from 1982 to 2000. Two features of *Scopus* possibly reject the latter explanation. First, over the past three years, *Scopus* has complemented the database's existing records that data back to 1788 and increased the depth of its content (Scopus, 2017). *Scopus* now includes over 1260 journals under the category of 'education' and over 300 journals under the category of 'construction and building'. The coverage of a wider array of peer-reviewed references makes *Scopus* more popular among researchers for article retrieval in the field of engineering education (e.g., Lundin et al., 2018; Thürer et al., 2018). Second, the Content Selection and Advisory Board was formed in 2009 to develop an objective system for the

inclusion and exclusion of journals in *Scopus* against transparent criteria. Both features of *Scopus* negate the risk of database selection bias. Thus, the finding about the development trend of CE publications can be drawn as:

I. The variations of annual CE publications suggest the trend of growing interest in the CE research from 2000 onwards.

<Please insert Fig. 1 here>

<Please insert Table 2 here>

Structure of the Body of CE Knowledge

Main Research Themes (Keyword Co-occurrence Analysis)

In scientific research, authors generally use keywords to concisely describe their core focuses and scopes (Hood and Wilson, 2001). Keyword co-occurrence analysis can map the keywords in terms of occurrence patterns and interrelations (van Eck and Waltman, 2014). Thus, this technique was chosen to identify the main themes in the CE research.

Prior to analysis, all data was divided into six groups based on the years of publication as belonging to 1982-1987, 1988-1993, 1994-1999, 2000-2005, 2006-2011, and 2012-2017. Then, keywords were merged if they carried the same connotation (e.g., "BIM", "building information model", "building information modeling", and "building information modelling"); Generic terms such as "China", "Hong Kong", and "United States" were also omitted. The organized data was imported to VOSviewer, in which the fractional counting method was selected and the minimum number of occurrences was set as one to cover as many keywords as possible. Using VOSviewer, six keyword co-occurrence maps were produced (see Fig. 2). In each map, one node represents a keyword, while the size of a node denotes the occurrence frequency of a keyword appearing in all publications. The link between two nodes represents two specific keywords appear together in a single publication.

The betweenness centrality of each keyword emerged within 2000-2005, 2006-2011, and 2012-2017 was computed using Pajek. Betweenness centrality is a measure of centrality in a graph based upon the shortest paths between graph vertices (Freeman, 1977). A node with higher betweenness centrality connects more groups of keywords than a node with lower betweenness

centrality. Table 3 illustrates the top ten keywords with the highest betweenness centralities. The betweenness centralities of keywords emerged before 2000 are not available because of the insufficient numbers of keywords covered during that period. Based on Fig. 2 and Table 3, the following findings can be derived, which focus on the changing numbers of keywords from map(a) to map(f) and interrelations between keywords in each map:

II. From 1982 to 1993, CE studies have covered a rather narrow range of topics, including civil engineering education, organizational behavior, and construction management, to name a few. These studies, meant to find an emphasis on the role of CE in teaching the managerial and organizational knowledge of construction, instead suggest a lack of attention to teaching and learning behaviors at that time. Since 1994, the subcategories in this field have become increasingly diverse, observed by the gradually more and more complex keyword co-occurrence maps.

III. In publications after 2000, while the managerial aspect of CE knowledge remained important, growing attention to the pedagogical approach also emerged (see the noticeable betweenness centralities of keywords such as "curriculum", "learning styles", "active learning" and "distance education" in Table 3). Many studies focused on how to utilize advanced technologies, for example, information technologies, computers, and virtual reality (VR), to actualize teaching methods such as simulation- and game-based teaching for CE. Compared to earlier studies, those post-2000 noticeably stressed how students can better absorb the knowledge.

IV. In studies published after 2006, new concepts of lean construction, sustainability, and building information modeling (BIM) have deeply caught the attention of CE researchers. In particular, both BIM and sustainability have gradually earned prominence in the CE research field. As shown in Table 3, the betweenness centrality of BIM increased from 0.108 to 0.130 during a ten-year period, while the betweenness centrality of sustainability also made the top ten keywords in map(f). Compared with BIM and sustainability, lean construction has floundered, holding only a minor position in the maps possibly because lean and sustainability overlap in a sense as concepts, raising a need for efforts that promote their integration (Huovila and Koskela, 1998).

<Please insert Fig. 2 here>

<Please insert Table 3 here>

Intellectual Structure (Bibliographic Coupling Analysis)

The semantic similarity measure of knowledge provides insight into the intellectual structure of a knowledge domain with cited documents as concept symbols. Bibliographic coupling (BC) and co-citation analysis are two key similarity solutions via the clustering of documents based upon existing co-citation patterns. BC analysis measures the number of references that two publications have in common. Co-citation analysis refers to the frequency with which one publication cites two other publications together (Osareh, 1996). BC analysis enjoys an important advantage over co-citation analysis because it enables direct analysis of the intellectual influences of publications rather than via indirect interpretations (Zhao and Strotmann, 2008). Especially in some fields (e.g., medicine), BC analysis perceptibly extends wider coverage and accuracy of clustering than co-citation analysis (Boyack and Klavans, 2010). Thus, this study adopted BC analysis.

BC analysis was conducted using VOSviewer, in which the minimum number of citations of a document was set as one. Documents that met this threshold, were published between 1987 and 2017, and shared at least one co-cited document with another document were included in the BC network as presented in Fig. 3. These documents were subdivided into fifteen clusters, manifest by the different colors in Fig. 3 and labeled from #1 to #15 as corresponds to Table 4.

The BC network has a VOS clustering quality value of 0.8115. The VOS quality function resembles, but slightly dominates, the popular modularity function since the former function does not suffer from the resolution limit problem as the latter does (Traag et al., 2011). Since a network with a quality value close to one indicates isolation between clusters in the network, it denotes CE studies have formed a network with loose relations between documents in different clusters.

The representative of a cluster shown in Table 4 is the citing document that has the most co-cited documents with all other citing documents in a cluster. The "total link strength" conveys the number of co-cited documents of a representative. Based on the principle of BC (Ma, 2010),

the representative could be considered the publication that shares the most similarity with other documents in theme within a cluster. The similarity relations between documents in a cluster are stable and static once the time boundaries of a bibliographic dataset are determined (Ma, 2010). Moreover, for each cluster, the value of the total link strength is relative to the number of documents close to or higher than one. This indicates close relations between documents within the same cluster (see Table 4). From Fig. 3 and Table 4, the following findings are derived:

V. In each of the 15 clusters in the BC network, the included documents were found to revolve around the same topic. Among all clusters, five enjoyed over ten documents. These five clusters' topics were: design and development of CE programs (cluster #1), teaching methods via the use of BIM or other technologies (cluster #2), game- or simulation-based pedagogies (cluster #3), advanced technologies in the education of sustainable construction (cluster #4), and information technologies in the education of "lean" construction (cluster #5). Notably documents from different clusters overlapped topics, and so, the total number of topics covered by all documents in the network proved less than fifteen.

VI. Out of the 232 CE studies in the bibliographic records, 127 shared similarities with other studies and occupied clusters of the BC network, signifying about half the publications of CE research shared no similarities with any other publication. Zhao and Strotmann (2008) argued that weak signals in BC analysis might imply research frontiers. However, with such considerable studies not belonging to any cluster of co-citations, CE research might face a variety of issues, such as lack of communication or conceptual debate between stakeholders.

VII. The isolation between clusters and close relations within clusters in the BC network suggests that the CE research has formed a network with publications connected rather via intra-cluster co-citations, but disconnected with publications in extraneous clusters. This feature implies that CE scholars may have overlooked the referencing of theories and methods from CE studies outside their clusters. As argued by Zahra (2007) and Nerur et al. (2008), a research area exhibiting such a feature indicates studies therein may have been built on limited sources of knowledge or even flawed credibility.

<Please insert Fig. 3 here>

<Please insert Table 4 here>

Prominent Journals for CE Studies (Direct Citation Analysis)

Direct citation analysis intuits the prominence of journals in a research field. Results of direct citation analysis are useful for both CE researchers to publish their work and for readers to access the right resources (Hosseini et al., 2018). Bibliographic records cover fifty-two journals, among which the citation relations were visualized as a citation network with thirty-seven clusters. The top ten journals, ranked by the accumulative number of CE publications, formed three noteworthy clusters as presented in Fig. 4. While the network of fifty-two journals has a VOS clustering quality value of 0.7369, the sub-network shown in Fig. 4 has a VOS clustering quality value of 0.4353.

Both measures of betweenness centrality and hyperlink-induced topic search (HITS) algorithm were used to analyze the citation network. The HITS algorithm, developed by Kleinberg (1999), gives a hub score of each node in a network to estimate the value of the node's links to other nodes. When employing HITS to rank scientific journals, a journal with a higher hub score may have received the same number of citations than a lower hub scored journal, but from a more important journal or journals. Table 5 summarizes the betweenness centrality and the hub score of each of the top ten journals, as well as the main topics covered by CE studies published in each journal. From Fig. 4 and Table 5's findings, the prominence of each journal publishing CE research is summarized below:

VIII. The smaller quality value of the sub-network (see Fig. 4) suggests that the citation relations among the top ten journals in different clusters are relatively closer than relations among all journals included by the entire network. Implicitly, CE studies published in the top ten journals have referenced each other more often compared with referencing studies published in other journals outside the top ten.

IX. Out of 232 CE studies in the bibliographic records, about 72% were published in the top ten journals. Among these journals, *Journal of Professional Issues in Engineering Education and Practice* (JPIEEP) ranked second. However, JPIEEP received the most citations and had the highest hub score (0.6265) regarding its published CE studies. Thus, JPIEEP stands out as the most prominent, influential outlet for CE studies. It has received citations from

important journals more often than citations received by any other journal in our dataset. Other important CE journals include *International Journal of Construction Education and Research* (IJCER) (hub score 0.5314), *Journal of Information Technology in Construction* (JITC) (hub score 0.4154), *Journal of Construction Engineering and Management* (hub score 0.3165), and *Automation in Construction* (AIC) (hub score 0.129).

X. JPIEEP also received the highest betweenness centrality (0.0908) in the citation network. Based on the principle of betweenness centrality, JPIEEP has the most diverse citation relations with other journals of all the journals in the dataset. This indicates that JPIEEP may play the most important role in disseminating CE research and information. Following JPIEEP, ranks JITC (betweenness centrality 0.0467), IJCER (betweenness centrality 0.0387), *Engineering, Construction and Architectural Management* (betweenness centrality 0.0307), and AIC (betweenness centrality 0.0204). This ranking differs from ranking by journals' hub scores, denoting that the prominence of a journal does not necessarily imply the diversity of its citation relations with other journals.

XI. From the main topics given in Table 5, the use of new teaching methods (e.g., simulation-, game-, BIM-, VR-based teaching) feature among the major focuses of CE studies published in the top ten journals. They constitute the main topics of seven of the listed journals. In second are topics about professional development and the development of different pedagogical methods, such as service learning, active learning, and distance education. What these studies often have in common is their focus on technological requirements to realize advanced teaching methods and pedagogies, suggesting a lack of attention to contextual issues (e.g., social impacts). The fact that topics about sustainability, knowledge creation, industry practice, and graduate employability are limited to a fewer number of journals, such as JPIEEP and JITC, likely confirms this (see Table 5). As does the observation that the only managerial and economic oriented journal, i.e., *Construction Management and Economics*, on the list of top CE research outlets has a zero hub score and betweenness centrality.

<Please insert Fig. 4 here>

<Please insert Table 5 here>

Scientific Collaboration in the CE Community (Co-authorship Analysis)

Co-authorship analysis has been regarded as one of the most tangible, well-documented ways of investigating scientific collaboration in a knowledge community. Co-authorship networks created by bibliometric methods can provide reliable information to almost every aspect of scientific collaboration (Glänzel and Schubert, 2004). In this paper, the scientific collaboration in the CE research community was identified based on the co-authorship relations both between authors and between countries/regions.

Notable Authors

There were 483 authors in the bibliographic records. Importing the information of all authors into VOSviewer formed a collaboration network with nineteen clusters with a VOS clustering quality value of 0.9892 (see Fig. 5). Each cluster was shaped by a group of authors who had published papers together or shared common co-authors. Among the 483 authors, sixty-six made up the first five clusters ranked by the number of authors in a cluster.

Table 6 presents hub scores and betweenness centralities of the top twelve authors in descending order respectively. In Table 6, authors belonging to clusters from #6 onwards were marked as "N". Informed by Lu et al. (2009), the hub score of an author implies the influences of this author based on the co-author relations he or she has created, while the betweenness centrality of an author indicates the diversity of his or her co-author relations. I.e. an author with high betweenness centrality suggests he or she has been active in publishing papers with different co-authors. Fig. 5 and Table 6 derived the below findings on the co-author relations:

XII. Cluster #4 is the most notable cluster among the collaboration network of authors. The first six authors with the highest hub cores, i.e., Elliott J.W. (0.5630), Bigelow B.F. (0.5238), Thevenin M.L. (0.4345), Bilbo D. (0.2438), Mathew M. (0.2358), and Ritter l. (0.2358), all populate cluster #4. This indicates that the most influential authors have formed a constant link via collaborative research. Regarding the diversity of co-author relations, Leung M.Y and Glick S. ties for first, each with betweenness centralities of 0.0007, followed by Bigelow B.F. with betweenness centrality of 0.0006, and Mccoy A.P., Pearce A.R., and Lu M. each with betweenness centralities of 0.0005.

XIII. Compared with the constant co-author relations between authors in the same cluster, the collaboration network of authors reveals an intellectual isolation between authors

from different clusters. In addition, many authors do not belong to any cluster as they have conducted their research alone rather than exchange and create knowledge through collaboration with other authors.

<Please insert Fig. 5 here>

<Please insert Table 6 here>

Influential Countries/Regions

Fig. 6 depicts the collaboration network of countries/regions with a VOS quality value of 0.7498. In the network, the size of each node denotes the number of publications co-written with authors from other countries/regions. Table 7 presents the first 8 countries/regions ranked by the hub score and betweenness centrality respectively. Based on Fig. 6 and Table 7, the following findings are drawn:

XIV. Out of forty countries/regions in the bibliographic records, twenty-three were included in the network, which formed ten collaboration clusters. This fair proportion of countries/regions included in the network implies that the existing CE knowledge may be developed based on acceptable cross-context cases and comparative studies. For researchers from the remaining seventeen countries/regions, excluded from the network, when they conduct CE studies, perhaps they should pay extra attention to the relevance and generalization of findings and knowledge they have derived.

XV. China (hub score 0.5346), the United States (hub score 0.4796), and Hong Kong (hub score 0.4786) stand out as the most influential countries/regions as they have created stable co-author relations with other influential countries/regions of the CE knowledge community. In terms of the diversity of international collaborations, the United States has built the most various collaborative links with other countries/regions, e.g., the United Kingdom, Australia, South Korea, and Hong Kong. In addition, the United States has published the most CE studies through collaborative research. This alleges that authors from the United States likely occupy the most important positions in the CE research community in the sense that they connect intensive research activities with authors from other influential countries/regions.

<Please insert Fig. 6 here>

<Please insert Table 7 here>

Discussions of Findings and Future CE Research

The findings reported above expose the current status and the development trend in CE research. CE began as early as the 1920s, however, it has only been since the beginning of the twenty-first century that an arresting research interest in CE has emerged. This growing trend in CE research coincides with the era of new labor requirements for embracing emerging tendencies and confirms the role of education in sustaining the development of the construction industry. Findings VIII-XI provided information about journals, which have recently published CE studies. Using proxy measures in terms of the number of CE publications, the betweenness centrality, and the hub score of a journal, *Journal of Professional Issues in Engineering Education and Practice* stands out as the most prominent journal in the CE research field, having the most diverse citation relations with other important journals and the second largest number of CE publications.

Findings III-VII and XI-XV manifest two key aspects of the current body of CE knowledge's limitations. First, findings III, IV, V, and XI, which relate to the main topics in the CE research, recent CE studies overwhelmingly focus on how to teach students to use advanced technologies (e.g., BIM and VR), or how to use these technologies to realize teaching methods (e.g., game- and simulation-based teaching). These findings, combined with analyses achieved by delving into representative papers, make the incomplete nature of the CE knowledge apparent. Important issues in relation to the interactive process between educators and students (e.g., the effectiveness of student learning) largely remain under-researched.

Second, findings V, VI, and VII of the BC analysis imply that, with some ten categories of topics covered, CE studies from one co-citation cluster hardly influence studies from other clusters, even when studies from different clusters focus on similar topics. Findings from XII-XV also echo similar inferences concerning the analysis of the scientific collaboration network in the CE knowledge community. Briefly, it is found that, while the influential CE researchers have created constant collaboration relations, many other CE researchers appear to have disregarded knowledge exchange and creation through collaborative research. Therefore, efforts to improve the cross-fertilization and integration of knowledge in the CE research field are needed.

Based on the limitations discussed above, the authors suggest three possible directions to extend the present body of knowledge in the CE research. Firstly, concerning the existing excessive focuses on the technology utilization in CE studies, the authors argue for research attention to the contextual factors and impact-focused topics, such as the performance evaluation of different pedagogical methods and the identification of best CE practices. Studies on these aspects, as pointed out by many CE researchers (e.g., El-adaway et al., 2015; Zhu and Ibrahim, 2017), could prove important and relevant given that knowledge gain should be an active and mutual process between educators and students.

Furthermore, sifting through the papers which formed finding IV confirms that students with construction-related majors and knowledge of BIM have been increasingly sought after by the industry. Many CE researchers have published articles about BIM education (e.g., Clevenger et al., 2012; Sacks and Pikas, 2013; Abdirad and Dossick, 2016). These studies, however, have mainly focused on the problem of teaching students to use BIM and providing solutions, such as designing standalone BIM courses to teach various BIM applications and merging BIM into the content of existing courses. They seem to have neglected other challenges related to BIM education, for instance when to insert BIM into current curricula and how to evaluate learning outcomes. The authors recommend future research be directed toward identifying suitable timing and strategies for arranging BIM coursework, as well as rubrics/frameworks for assessing BIM courses. This can both help measure students' BIM skills and knowledge as well as learning outcomes.

Last but not least, in parallel with the lack of knowledge exchange and collaborative research in the CE research field, the authors call for greater attention be paid to the gap between CE and industrial requirements. Researchers recognize the difficulty of finding CE faculty members with extensive industry experience (e.g., Arlett et al., 2015), which prevents CE students from building the necessary competencies to succeed in their future careers (Becker et al., 2011). Scott (2016) stressed the need to stay abreast of and teach students what they ultimately need to know in order to become effective professionals rather than impart static knowledge. To circumvent these challenges, it is important to develop a robust relationship between CE and the industry. Thus, another further direction of CE research could be investigating practical structures and other issues in relation to forming industry-university partnerships for CE.

Conclusions

In recent decades, CE research has stimulated a rising amount of attention to the establishment of construction specialty programs in many universities or educational institutions. Positioned as the first bibliometric review of the CE research, this paper analyzed the CE literature over a relatively long period of time, 1982 to 2017, revealed the shifts in the body of CE knowledge, and identified the current status and research directions of the field. The adopted bibliometric techniques included keyword co-occurrence analysis, BC analysis, direct citation analysis, and co-authorship analysis. These four techniques were directed to discover meaningful patterns therein, including the popular and focused research themes, research collaboration between authors, and intellectual influences of journals and countries/regions.

Through the bibliographic analysis, this paper derived a total of fifteen findings. The implications of these findings and possible future CE research were also discussed. Primarily, present CE research has shown a bias towards the utilization of technologies in education, calling for a shift in emphasis toward contextual factors and impact-focused topics. Addressing the gaps between CE and industrial requirements is also needed. In addition, significant isolation between formed groups (e.g., co-citation clusters, collaboration networks) exists, underscoring the necessity of enhancing integration and generalization in CE knowledge derived from different subfields. By providing these aspects of knowledge, this paper seeks to serve as an important reference for other researchers and practitioners in their exploration and understanding of CE.

Acknowledgments

The authors would like to thank all editors and reviewers for their constructive comments.

References

Abdirad, H., and Dossick, C. S. (2016). BIM curriculum design in architecture, engineering, and construction education: A systematic review. *Journal of Information Technology in Construction*, 21(17), 250-271.

Abudayyeh, O., Russell, J., Johnston, D., and Rowings, J. (2000). Construction engineering and management undergraduate education. *Journal of Construction Engineering and Management*, 126(3), 169-175.

566 Arlett, C., Lamb, F., Dales, R., Willis, L., and Hurdle, E. (2010). Meeting the needs of industry:
567 the drivers for change in engineering education. *Engineering Education*, 5(2), 18-25.

568 Ball, M., Lizieri, C., and MacGregor, B. (2012). *The economics of commercial property*
569 *markets*. Routledge.

570 Barr, B. (2008). UK civil engineering education in the twenty-first century. in *Proceedings of*
571 *the Institution of Civil Engineers-Management, Procurement and Law*, 161(1), 17-23.

572 Becerik-Gerber, B., Gerber, D. J., and Ku, K. (2011). The pace of technological innovation in
573 architecture, engineering, and construction education: integrating recent trends into the
574 curricula. *Journal of Information Technology in Construction*, 16(24), 411-432.

575 Becker, T. C., Jaselskis, E. J., and McDermott, C. P. (2011). Implications of construction
576 industry trends on the educational requirements for future construction professionals.
577 In *Proceedings of 47th ASC Annual International Conference. Omaha, Nebraska,*
578 *United States*.

579 Boyack, K. W., and Klavans, R. (2010). Co-citation analysis, bibliographic coupling, and
580 direct citation: Which citation approach represents the research front most accurately?
581 *Journal of the Association for Information Science and Technology*, 61(12), 2389-2404.

582 Carr, W., and Kemmis, S. (2003). *Becoming critical: education knowledge and action research*.
583 Routledge.

584 Clevenger, C. M., Brothers, H., Abdallah, M., and Wolf, K. (2017). Initial assessment of a
585 newly launched interdisciplinary construction engineering management graduate
586 program. *Journal of Professional Issues in Engineering Education and Practice*, 143(3),
587 04017001.

588 Clevenger, C. M., Glick, S., and del Puerto, C. L. (2012). Interoperable learning leveraging
589 building information modeling (BIM) in construction education. *International Journal*
590 *of Construction Education and Research*, 8(2), 101-118.

591 Chinowsky, P. S., Brown, H., Szajnman, A., and Realph, A. (2006). Developing knowledge
592 landscapes through project-based learning. *Journal of Professional Issues in*
593 *Engineering Education and Practice*, 132(2), 118-124.

594 El-adaway, I., Pierrakos, O., and Truax, D. (2015). Sustainable construction education using
595 problem-based learning and service learning pedagogies. *Journal of Professional*
596 *Issues in Engineering Education and Practice*, 141(1), 05014002.

597 Freeman, L. C. (1977). A set of measures of centrality based on betweenness. *Sociometry*, 35-
598 41.

599 Garrison, D. R., Anderson, T., and Archer, W. (1999). Critical inquiry in a text-based
600 environment: Computer conferencing in higher education. *The Internet and Higher*
601 *Education*, 2(2-3), 87-105.

602 Glänzel, W. and Schubert, A. (2004). *Analysing scientific networks through co-authorship. In*
603 *Handbook of quantitative science and technology research (pp. 257-276).* Springer,
604 Dordrecht.

605 Glover, R. W., Long, D. W., Haas, C. T., and Alemany, C. (1999). *Return-on-investment (ROI)*
606 *Analysis of education and training in the construction industry (Vol. 6)*. Center for
607 Construction Industry Studies.

608 Hood, W., and Wilson, C. (2001). The literature of bibliometrics, scientometrics, and
609 informetrics. *Scientometrics*, 52(2), 291-314.

610 Hosseini, M. R., Martek, I., Zavadskas, E. K., Aibinu, A. A., Arashpour, M., and Chileshe, N.
611 (2018). Critical evaluation of off-site construction research: A Scientometric analysis.
612 *Automation in Construction*, 87, 235-247.

613 Huovila, P., and Koskela, L. (1998). Contribution of the principles of lean construction to meet
614 the challenges of sustainable development. In *6th Annual Conference of the*
615 *International Group for Lean Construction*. Guaruja, São Paulo, Brazil (pp. 13-15).

616 Krishnamoorthy, G., Ramakrishnan, J., and Devi, S. (2009). Bibliometric analysis of literature
617 on diabetes (1995–2004). *Annals of Library and Information Studies*, 56, 150-155.

618 Kleinberg, J. M. (1999). Authoritative sources in a hyperlinked environment. *Journal of the*
619 *ACM*, 46(5), 604-632.

620 Lu, H., and Feng, Y. (2009). A measure of authors' centrality in co-authorship networks based
621 on the distribution of collaborative relationships. *Scientometrics*, 81(2), 499.

622 Lundin, M., Rensfeldt, A. B., Hillman, T., Lantz-Andersson, A., and Peterson, L. (2018).
623 Higher education dominance and siloed knowledge: a systematic review of flipped
624 classroom research. *International Journal of Educational Technology in Higher*
625 *Education*, 15(1), 20.

626 Ma, R. (2012). Author bibliographic coupling analysis: A test based on a Chinese academic
627 database. *Journal of Informetrics*, 6(4), 532-542.

628 Mahapatra, M. (1985). On the validity of the theory of exponential growth of scientific
629 literature. in *Proceedings of the 15th Indian Association of Special Libraries and*
630 *Information Centres Conference*, Bangalore (pp. 61-70).

631 Meho, L. I., and Rogers, Y. (2008). Citation counting, citation ranking, and h-index of human-
632 computer interaction researchers: a comparison of Scopus and Web of Science. *Journal*
633 *of the Association for Information Science and Technology*, 59(11), 1711-1726.

634 Murray, P. E., and Cotgrave, A. J. (2007). Sustainability literacy: the future paradigm for
635 construction education? *Structural Survey*, 25(1), 7-23.

636 Nerur, S. P., Rasheed, A. A., & Natarajan, V. (2008). The intellectual structure of the strategic
637 management field: An author co-citation analysis. *Strategic Management Journal*,
638 29(3), 319-336.

639 Oglesby, C. H. (1990). Dilemmas facing construction education and research in 1990s. *Journal*
640 *of Construction Engineering and Management*, 116(1), 4-17.

641 Osareh, F. (1996). Bibliometrics, citation analysis and co-citation analysis: A review of
642 literature I. *Libri*, 46(3), 149-158.

643 Park, C. S., Le, Q. T., Pedro, A., and Lim, C. R. (2016). Interactive building anatomy modeling
644 for experiential building construction education. *Journal of Professional Issues in*
645 *Engineering Education and Practice*, 142(3), 04015019.

646 Perrenet, J. C., Bouhuijs, P. A. J., and Smits, J. G. M. M. (2000). The suitability of problem-
647 based learning for engineering education: theory and practice. *Teaching in Higher*
648 *Education*, 5(3), 345-358.

649 Robichaud, L. B., and Anantatmula, V. S. (2010). Greening project management practices for
650 sustainable construction. *Journal of Management in Engineering*, 27(1), 48-57.

651 Sacks, R., and Pikas, E. (2013). Building information modeling education for construction
652 engineering and management. I: Industry requirements, state of the art, and gap
653 analysis. *Journal of Construction Engineering and Management*, 139(11), 04013016.

654 Scopus (2017). Scopus content: High quality, historical depth and expert curation. Available
655 at: https://www.elsevier.com/solutions/scopus/how-scopus-works/content <accessed
656 on 14 Jun 2018>

657 Scott, L. M. (2016). Theory and research in construction education: the case for
658 pragmatism. *Construction Management and Economics*, 34(7-8), 552-560.

659 Smith, N. M., Smith, J. M., Battalora, L. A., and Teschner, B. A. (2018). Industry–University
660 Partnerships: Engineering education and corporate social responsibility. *Journal of*
661 *Professional Issues in Engineering Education and Practice*, *144*(3), 04018002.

662 Teizer, J., Cheng, T., and Fang, Y. (2013). Location tracking and data visualization technology
663 to advance construction ironworkers' education and training in safety and productivity.
664 *Automation in Construction*, 35, 53-68.

665 Thürer, M., Tomašević, I., Stevenson, M., Qu, T., and Huisingh, D. (2018). A systematic
666 review of the literature on integrating sustainability into engineering curricula. *Journal*
667 *of Cleaner Production*, 181, 608-617.

668 Traag, V.A., Van Dooren, P., and Nesterov, Y. (2011). Narrow scope for resolution limit-free
669 community detection. *Physical Review E*, 84(1), 016114.

670 van Eck, N. J., and Waltman, L. (2014). *Visualizing bibliometric networks. In Measuring*
671 *scholarly impact (pp. 285-320)*. Springer International Publishing.

672 van Raan, A. F. (2005). For your citations only? Hot topics in bibliometric
673 analysis. *Measurement: Interdisciplinary Research and Perspectives*, 3(1), 50-62.

674 Webster, J., and Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a
675 literature review. *MIS Quarterly*, xiii-xxiii.

676 Zahra, S. A. (2007). Contextualizing theory building in entrepreneurship research. *Journal of*
677 *Business Venturing*, 22(3), 443-452.

678 Zhao, D., and Strotmann, A. (2008). Evolution of research activities and intellectual influences
679 in information science 1996–2005: Introducing author bibliographic-coupling analysis.
680 *Journal of the Association for Information Science and Technology*, 59(13), 2070-2086.

681 Zhu, Y., and Ibrahim, M. (2017). Application of structure–behavior–function (SBF) theory to
682 construction education. *International Journal of Construction Management*, 17(4),
683 264-279.