Global Scientific JOURNALS

GSJ: Volume 7, Issue 6, June 2019, Online: ISSN 2320-9186
www.globalscientificjournal.com

A REVIEW ON BUILDING INFORMATION MODELING FOR Off-SITE CONSTRUCTION

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A B S T R A C T

Building Information Modelling (BIM) and off -site construction (OSC) are increasingly applied in the archi- tecture, engineering and construction (AEC) industry due to their many benefits to project stakeholders, such as enhanced design visualization, improved data exchanges, reduced construction waste, improved productivity, and higher product quality. Substantial research eff orts have thus been devoted to these topics in recent decades, resulting in a large amount of literature regarding BIM and OSC. This research explores the state-of-the-art in BIM for OSC by means of a bibliometric-qualitative review method. The objective of this research is to uncover the synthesis between BIM and OSC and to identify research trends as well as gaps in knowledge that can be addressed in future research on BIM for OSC. Science maps are constructed by means of bibliometric analysis in order to objectively identify the main research topics of these two fields both separately and jointly based on identified academic publications from Scopus (i.e., 4395 publications on BIM, 2841 publications on OSC, and 113 publications on BIM for OSC). A qualitative review is further conducted on 77 screened research publications (including articles, reviews, conference papers) with a particular focus on BIM for OSC. Through quantitative analysis and in-depth discussion of BIM for OSC, research gaps are identified, and future directions are further proposed as follows: BIM-based generative design for prefabrication, cloud BIM-based data exchange for OSC, robotics and 3D printing for OSC, BIM-enabled big data analytics toward best OSC practice, benefits and its assessment model of BIM for OSC. This research contributes to the body of knowledge by synthesizing the state of the art of BIM for OSC and exposing the research needs in this area in order to improve AEC practice.

Introduction

Building information modelling (BIM) and off -site construction (OSC) are two paradigms that have been claimed to potentially address the long-standing issues such as lower effi ciency and productivity in the construction industry and profoundly innovate the construction in- dustry [1]. According to the National Building Information Model Standard Project Committee, BIM is defined as “a digital representation of physical and functional characteristics of a facility,” while a BIM is “a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition” [2]. OSC refers to a construction method that “brings on-site construction works into a climate-con- trolled facility where advanced machinery and manufacturing tech- nologies can be utilized to prefabricate buildings in a standardized and effi cient manner” [3]. Indeed, BIM and OSC are highly interrelated and could be applied together to maximize their benefits to the construction research needs regarding BIM for OSC. This mixed-review can eliminate biased conclusion and subjective interpretation of domain knowledge and research trends while providing a deeper insight on research gaps and needs. By doing so, this research theoretically contributes to the body of knowledge in two folds: 1) research topics and trends regarding BIM for OSC research is

evaluated and identified in an objective manner; and 2) in-depth integration of BIM and OSC, as well as research gaps and needs, are revealed via in-depth qualitative analysis.

The remainder of this paper is organized as follows. In Section 2, previous works related to BIM and OSC topics are summarized. In Section 3, research methodology (i.e., mixed-review method) is illu- strated in detail. Subsequently, the results and findings are described in Section 4. Section 5 discusses the findings from the bibliometric and systematic analysis of existing literature review and identifies the gap in knowledge and future directions regarding the joint research of BIM and OSC. The final section concludes by highlighting the research contribution of this paper.

Previous work

This section discusses existing literature review on BIM and OSC to clarify the need of the mixed review on BIM for OSC presented in this paper.

BIM-related review

In 2010, Becerik-Gerber and Kensek [5] identified research trends of BIM in the AEC industry by means of workshop discussions. The iden- tified research areas include: (1) the investigation of centralized data- base and linked data, (2) BIM coordination for sustainable design, (3) integrated project delivery (IPD) for promoting BIM, (4) education on IPD, BIM, and sustainability, (5) return on investment, and (6) man- agement issues on BIM-based projects. Subsequently, Cerovsek [6] presented a comprehensive review of BIM technological development from the perspective of the model, modelling tool, communicative in- tent, individual project work, collaborative project work, and standar- dization with ISO STEP. Soust-Verdaguer et al. [7] critically reviewed studies on BIM-based life cycle assessment (LCA) and discussed how BIM can simplify data input and optimize data output for LCA. Simi- larly, Eleftheriadis et al. [8] reviewed continuous BIM developments for LCA, aiming at the formalization of research guidelines for a BIM-based decision-making paradigm in the sustainable energy domain. Pärn et al.
[9] conducted a comprehensive review of scientific literature on BIM and facility management (FM), with a focus on the integration of BIM- FM for the operation and maintenance phase of building. Bradley et al.
[10] presented a systematic review of BIM research in the infrastructure domain and identified four research gaps regarding BIM for infra- structure: (1) lack of a common data format, (2) lack of holistic in- formation management, (3) misalignment of the business process with the BIM process, and (4) missing information governance and data usefulness definition. With the increasing popularity of cloud com- puting technology, Wong et al. [11] explored the literature on cloud- BIM in the construction sector, concluding that more research eff orts should be made toward the application of cloud-BIM for post-con- struction stages of building lifecycle management. Saieg et al. [12] conducted a systematic literature review of BIM, lean, and sustain- ability research for a better understanding of their synergies for the AEC industry. Lu et al. [13] investigated the connection between BIM and green buildings by conducting an in-depth review of scientific literature between 1999 and 2016. More recently, Antwi-Afari et al. [14] re- viewed studies on critical success factors for BIM implementation be- tween 2005 and 2015, concluding that collaboration in the AEC sta- keholders, earlier and accurate 3D design visualization, coordination and planning of construction works, improved information exchange and

knowledge management, and enhanced site layout planning and site safety are common factors for successful BIM implementation.

Other research, such as Ding et al. [15], Succar [16], and Singh et al. [17], also summarized the BIM-related research to provide a research and implementation framework for both academia and industry.

On the contrary, there are a few attempts that apply the quantitative approach in BIM literature review. For example, Yalcinkaya & Singh [18] applied latent semantic analysis to identify 12 principal research areas and 90 specific research themes in BIM research. Li et al. [21] used a bibliometric approach to summarize domains knowledge of BIM based on 1874 academic papers related to BIM. Santos et al. [22] also conducted a bibliometric analysis of existing BIM literature between 2005 and 2015 and categorizd research eff orts into eight groups using content analysis: (1) BIM adoption and standardization, (2) BIM and spatial information, (3) BIM programming, (4) collaborative environ- ments and interoperability, (5) construction management, facilities management and safety analysis, (6) image processing, laser scanning and augmented reality, (7) sustainable construction, and (8) BIM re- views. Oraee et al. [23] conducted a bibliometric analysis of 1031 BIM studies and a critical review of 62 papers on collaboration in BIM-based construction networks. Their study revealed that previous research in promoting BIM-enabled project collaboration primarily focuses on BIM- related technology issues, rather than managerial antecedents. As a complement, He et al. [24] concluded a scientometric analysis of the managerial areas of BIM in order to seek new insights into BIM-based project management. Zhao [25] performed a scientometric review of BIM research published between 2005 and 2016 and provided a land- scape of BIM research with respect to co-authorship, regions and in- stitutions, co-occurring subject categories, co-occurring keywords, journal co-citation, author co-citation, and document co-citation. Hos- seini et al. [26] applied systematic forensic techniques to illustrate a clear picture of the body of knowledge on BIM from 2444 academic publications. However, these quantitative reviews on BIM have been limited to summarizing research topics on BIM and have not included in-depth qualitative discussion of existing literature for the purpose of shaping future research.

OSC-related review

With the dramatically increasing research dedicated to BIM, OSC is also attracting a growing attention from both industry and academia in the AEC industry. Kamali & Hewage [28] comprehensively summarized the benefits associated with OSC methods, such as a shortened sche- dule, improved safety and quality, higher effi ciency and reduced waste. For this reason, a large amount of research has been devoted to OSC in the AEC industry in past decades. Along with the growing body of knowledge regarding OSC, Li et al. [29] summarized a systematic re- view on the management of prefabricated construction (MPC) and identified the main MPC topics as "industry prospect," "development and application," "performance evaluation," "environment for tech- nology application," and "transportation and as-sembly strategies." Mostafa et al. [30] systematically synthesized the state-of-the-art research on OSC with a particular focus on the use of lean and agile principles as well as simulation in OSC. More recently, Hosseini et al. [26,27] presented the state of off -site construction re- search based on the

scientometric analysis, though without qualita- tively reviewing existing literature for the purpose of identifying re- search needs. Table 1 tabulates existing reviews with respect to BIM and OSC.

With respect to the joint research of BIM and OSC, previous research mainly focuses on how BIM can be used in OSC. For instance, Abanda et al. [31] studied the impacts of BIM on OSC in order to address the following questions: (1) how BIM can be used in OSC; (2) how BIM can overcome barriers hindering the adoption of OSC; and (3) what are the quantitative benefits of BIM for OSC. Although BIM has been advocated for its potential to facilitate OSC, as reported by Abanda et al. [31], limited research eff orts have attempted to synthesize research trends and to identify research directions in BIM for OSC. In particular, few

Table 1
Summary of literature review on BIM and OSC.

Review article	Research method	Research theme BIM	OSC
Antwi-Afari et al. [14]	Systematic critical review	x	Becerik-Gerber and Kensek
Workshop discussion [5]		x	
Bradley et al. [10]	Systematic review	x	
Cerovsek [6]	Critical review	x	
Chen et al. [32]	Critical review	x	
Ding et al. [15]	Critical review	x	
Eleftheriadis et al. [8]	Critical review	x	
He et al. [24]	Scientometric analysis	x	
Hosseini et al. [26]	Scientometric analysis		x
Hosseini et al. [27]	Social network analysis	x	
Kamali and Hewage [28]	Critical review		x
Li et al. [21]	Bibliometric analysis	x	
Li et al. [29]	Critical review		x
Lu et al. [13]	Critical review	x	
Mostafa et al. [30]	Systematic review		x
Oraee et al. [23]	Bibliometric analysis	x	
Pärn et al. [9]	Critical review	x	
Saieg et al. [12]	Systematic review	x	
Santos et al. [22]	Bibliometric analysis	x	
Shou et al. [121]	Critical review	x	
Singh et al. [17]	Focus group interviews and critical review	x	
Soust-Verdaguer et al. [7]	Critical review	x	
Succar [16]	Critical review	x	
Volk et al. [192]	Systematic review	x	
Wong et al. [11]	Systematic review	x	
Yalcinkaya and Singh [18]	Latent semantic analysis	x	
Zhao [25]	Scientometric analysis	x	

systematic reviews were carried out to delineate the state-of-the-art development of BIM and OSC and their interconnections.

Research methodology

The objective of this research is to synthesize the domain knowledge and to identify the research needs and future research direction within the field of BIM for OSC in the construction industry. Toward this ob- jective, a “mixed-review method” is employed in this study. In general, this method consists of quantitative review (i.e., bibliometric approach) and qualitative review (i.e., systematic approach), so that it is capable of eliminating biased conclusion and subjective

interpretation while providing an in-depth understanding of domain knowledge and re- search trends [33]. at visualizing structural and dynamic aspects of scientific research [38]. Bibliometric mapping serves as an important technique within the field of bibliometrics which visualizes the knowledge domain and relation- ships among articles, journals, and so forth [39]. Bibliometric mapping is used in this research to identify the knowledge domain and research trends regarding BIM and OSC on the basis of the existing literature. Meanwhile, a systematic review is carried out in order to provide a comprehensive view of existing research for the purpose of identifying gaps in the body of knowledge and anticipating future research direc- tions [23,40,41]. As a consequence, a mixed-review method is devel- oped to integrate bibliometric and systematic reviews in order to con- struct the full picture of the reviewed topic while singling out certain key areas in order to ensure an in-depth investigation. This mixed-re- view method is proposed based on the rationale of underlying mixed method research, namely, triangulation, complementary, development,

Mixed-review method

The mixed method usually refers to a methodology for conducting research that integrates quantitative and qualitative methodologies within a single research [34]. The goal of the mixed method is to utilize the strengths and minimize the weaknesses of both qualitative and quantitative methods [35]. In this paper, we take advantage of the mixed method to gain in-depth understanding of the reviewed topic while off setting the weaknesses inherent in using either the quantitative or qualitative method in isolation. There are five rationales underlying the mixed research method according to Greene et al. [36]: (1) trian- gulation: the mixed method can be used to achieve mutual corrobora- tion between quantitative and qualitative; (2) complementarity: the results from one method can be used to describe or enhance the other;

(3) development design: the sequential implementation of the two methods gives the latter opportunities to capitalize on the benefits of the former; (4) initiation: the mixed method can be applied in order to identify whether there is any paradox and contradiction in the findings, which helps to improve the research design; (5) expansion: the scope, breadth, and range of the research can be expanded by using diff erent methods. These five rationales not only motivate the use of the mixed- review method, but they also serve to shape the research design. The mixed-review method, as a practical application of mixed method re- search, combines the quantitative review method and qualitative re- view method in the review process [37]. It can reduce the influence of subjective judgement of the manual qualitative review method and improve the depth and understanding of the results of the quantitative review method [33,37]. Bibliometric review is chosen as the quantita- tive method in the present research, while systematic review is chosen as the qualitative method. The description and benefits of each methodare expounded upon below. The bibliometric approach is a statistical analysis method that aims systematic reviews were carried out to delineate the state-of-the-art development of BIM and OSC and their interconnections.

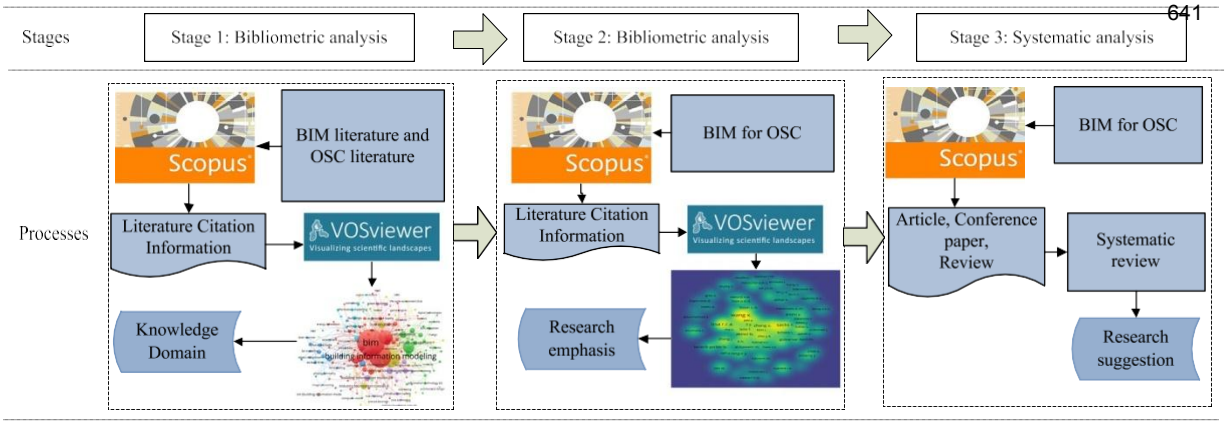

Fig. 1. Overview of research methodology.

Data acquisition

Data acquisition of existing literature is crucial in this research since it determines the scientific articles from which the conclusion will be drawn. For this reason, the database and searching strategy are care- fully selected. In this research, Scopus was chosen as the literature database. The reasons for selecting Scopus are as follows: (1) it has a relatively wide range of coverage in the domain of construction re- search compared with other databases such as Web of Science, Google Scholar, and PubMed [26,27,(424),4i5t]i;s a better choice for inter- disciplinary research topics, such as BIM and OSC, than Web of Science [45]; and (3) it has a wide range of coverage on journal publications [46].

Existing literature related to BIM in this database was then retrieved by using keywords, "BIM" and "building information model□". (It should be noted that the wildcard character is used to capture re- levant variations of a word, such as "building information model," "building information modelling," and "building information mod- eling," as shown in Table 2). To obtain a comprehensive dataset of OSC research, several studies, including cao et al. [47], Hosseini et al. [27], and Mao et al. [48], are referred to in determining the keywords. Ac- cordingly, the keywords selected were: "Off -site construction" OR "Off site construction" OR "Off site construction" OR "Off site manufacturing" OR "Off site manufacture" OR "Off -site manufacturing" OR "Off -site

3.3. Systematic analysis (stage 3)

Following the bibliographic analysis in stages 1 and 2, a qualitative

analysis of carefully selected papers was conducted (as shown in Fig. 1). The task is performed manually by the research team; as a result, re- search themes of each paper were summarized and discussed among the team. The purpose of qualitative analysis, it should be noted, is to provide an in-depth discussion and deeper insights regarding BIM for OSC and shed light on the needs for future research. The data acqui- sition method in this stage is similar to the one in Stage 2. Specifically, the first and second queries in Table 2 are combined in order to retrieve existing literature related to BIM for OSC. However, some resulting articles, such as duplicated or topic unrelated, need to be removed for the systematic analysis. As a result, screening processes are carried out before the systematic analysis of the targeted literature. Afterwards, identified academic articles are reviewed one-by-one, and categorized based on their research focus considering the lifecycle of the OSC process and bibliometric analysis results. On this basis, an in-depth discussion on BIM research in OSC is presented to inform future re- search.

Table 3
Identified academic journals and number of articles from 2003 to Aug 2018.

Journal/conference title	Number of articles

	BIM	OSC	BIM for OSC
ACI structural journal	0	3	0
Advanced engineering informatics	61	0	0
Applied mechanics and materials	72	60	4
Automation in construction	277	31	8
Canadian journal of civil engineering	8	9	0
Computer-aided civil and infrastructure engineering	8	1	0
Concrete London	4	32	0
Congress on computing in civil engineering proceedings	84	4	2
Construction and building materials	1	15	0
Construction innovation	30	11	1
Construction management and economics	15	23	1
Engineering structures	0	25	0
Journal of bridge engineering	1	5	0
Journal of computing in civil engineering	59	5	1
Journal of construction engineering and management	65	12	1
Journal of information technology in construction	58	0	0
PCI journal	3	9	1
Procedia engineering	113	33	3

Results and findings

Overview

The keyword search strategies listed in Table 2 were employed to identify relevant academic articles and their journals and conferences, which have been partially summarized in Table 2 and Table 3. Notably, the number of resulting BIM publications is quite low due to the use of "building information model□" as keyword to search the academic da- tabase; by contrast, while 4D modelling and product modelling, which are the terms used for BIM in the early 2000s, were not included in the search. As shown in Table 3, the majority of academic publications on BIM and OSC are found in the top journals in the field, including Au- tomation in Construction, Journal of Computing in Civil Engineering, Con- struction Management and Economics, Journal of Construction Engineering and Management, Advanced Engineering Informatics, Journal of Informa- tion Technology in Construction, and Computer-Aided Civil and Infra- structure Engineering. Among these journals, Automation in Construction is the journal that includes the most publications on these three topics. The next most productive publication forum is a conference proceeding, Procedia Engineering. This proceeding makes significant contributions to the field of BIM and OSC; however, the number of publications it in- cludes on BIM for OSC is not as outstanding as for the other two topics. Fig. 2 shows how the number of publications on the three topics under review (OSC, BIM, BIM for OSC) varies each year. Publications on OSC showed an overall upward trend since 2003, while the curve for

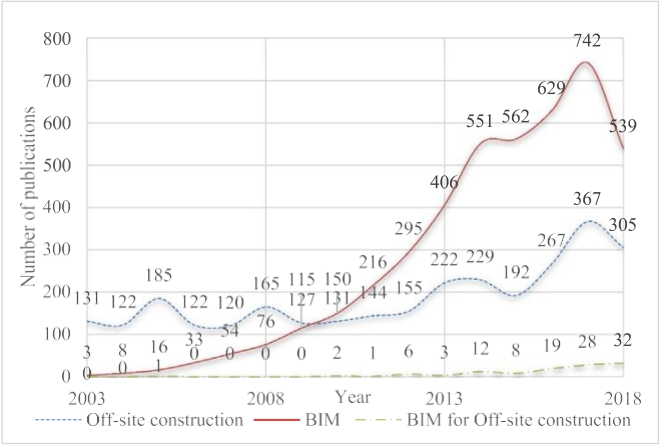

Fig. 2. Variations in the number of published studies on OSC, BIM and BIM for OSC (2003–Aug 2018).

BIM publications showed a rapid increase since 2005. The number of publications on BIM for OSC is relatively small, compared with the number of publications on both OSC and BIM, of which there were 32 in 2018. The trend shows a growth state, indicating an increasing atten- tion to the application of BIM in the area of OSC. The burst in BIM for

OSC research occurred in 2014, when the number of publications ex- ceeded 10 for the first time. This trend has continued until now. (Note that data was collected in August 2018, which means that it does not include the complete data for 2018. This explains the lower numbers for 2018 shown in Fig. 2 and the drop from the previous trend.) Based on the details included in Fig. 2 and Table 3, it can be shown that, while substantial research has been conducted on BIM and OSC topics, fewer endeavours have been made into BIM for OSC research.

Bibliometric analysis

BIM and OSC

To construct the knowledge domain of BIM and OSC, keyword co- occurrence in each research area was mapped using VOSviewer. The network visualization was chosen to demonstrate the results of bibliometric analysis on BIM and OSC literature. The output of the VOSviewer (i.e., Network Visualization) is distance-based maps in which the distance between two items reflects the strength of the relation between the items [39]. A smaller distance generally indicates a stronger relationship. The item label size reflects the number of publications in which the term was found. A bigger label size indicates that more publications contain this item. Diff erent colours represent diff erent groups of items that clustered by the clustering technique of VOSviewer [49].

Co-occurrence analysis of author keywords in BIM. The use of author keywords for bibliometric analysis to describe the patterns in existing research is recommended by a few studies, including Lee and Su [50] and van Eck and Waltman [44]. More recently, an increasing number of studies, such as reviews of emerging trends in global PPP research [51], BIM-based collaboration [23], mapping knowledge domains of BIM [21] and citation analysis of BIM [26], have employed this approach to investigate the knowledge base and identify key research areas in the construction research. As a result, they are chosen for the present research as the basis for developing the co-occurrence map for a better understanding of current research patterns, topics, and relationships. Information of 4395 publications obtained from Scopus was fed into the VOSviewer. The minimum number of occurrences of a keyword was set at 20 so that 38 of the 6410 keywords meet the threshold. This threshold selection was based on two aspects: (1) existing bibliometric literature review (e.g., [23,26,27]); (2) multiple experiments to generate the optimal graphics for research clusters. Other threshold selections were based on the same criteria in this research. The co-occurrence keywords are grouped into several clusters with various colours in Fig. 3. The detailed quantity information of each of the keywords in Fig. 3 (all greater than 20) is tabulated in Table 4. The occurrence shows the number of occurrences of each keyword from the author keywords retrieved from the 4395 citations. For example, other than the keyword BIM, IFC (industry foundation classes) is the one that appears most frequently among all the keywords, which indicates that it has been investigated extensively in the existing research.

The average year published shows the average time period in which a given keyword has been investigated by researches. For example, topics such as IFC, interoperability, IPD, and lean construction received more attention around 2014, while studies focusing on point cloud, energy effi ciency, green building, and Internet of Things (IoT), were published with greatest frequency during the period 2016 to 2017, indicating that the latter represent emerging themes in BIM research. The “links” are the number of linkages between a given item and other ones, while the total link strength reflects the total strength linked with a specific item [52]. For instance, the total link strength of OSC is 36, which is in the middle level of all the keywords and indicates the strong inter-relatedness between BIM and OSC.

Based on the research clusters in Fig. 3 and the research density obtained from Table 4, several findings were identified and are sum- marized as follows:

(1) Interoperability and data management (yellow cluster, lower-left; green cluster, middle-

left)

One major benefit of BIM in the AEC industry is enhanced work effi ciency through interoperability [53]. BIM is intended to minimize the rework of modelling building information for diff erent engineering purposes and to facilitate decision-making in various aspects of the AEC industry [54]. As a result, substantial eff orts were dedicated to data exchange among BIM applications, resulting in a large number of publications in the cluster of interoperability. Keywords such as IFC, interoperability, semantic web, ontology, and knowledge management frequently appear in BIM-related research. As early as the 1990s, re- searchers and industry practitioners were attempting to address inter- operability by means of standardization. In this context, IFC was pro- posed as a neutral data format for building information exchange for the AEC industry [55,56] and has been continuously supplemented over years. To date, IFC is capable of describing rich building information (such as geometry information, material information, vendor

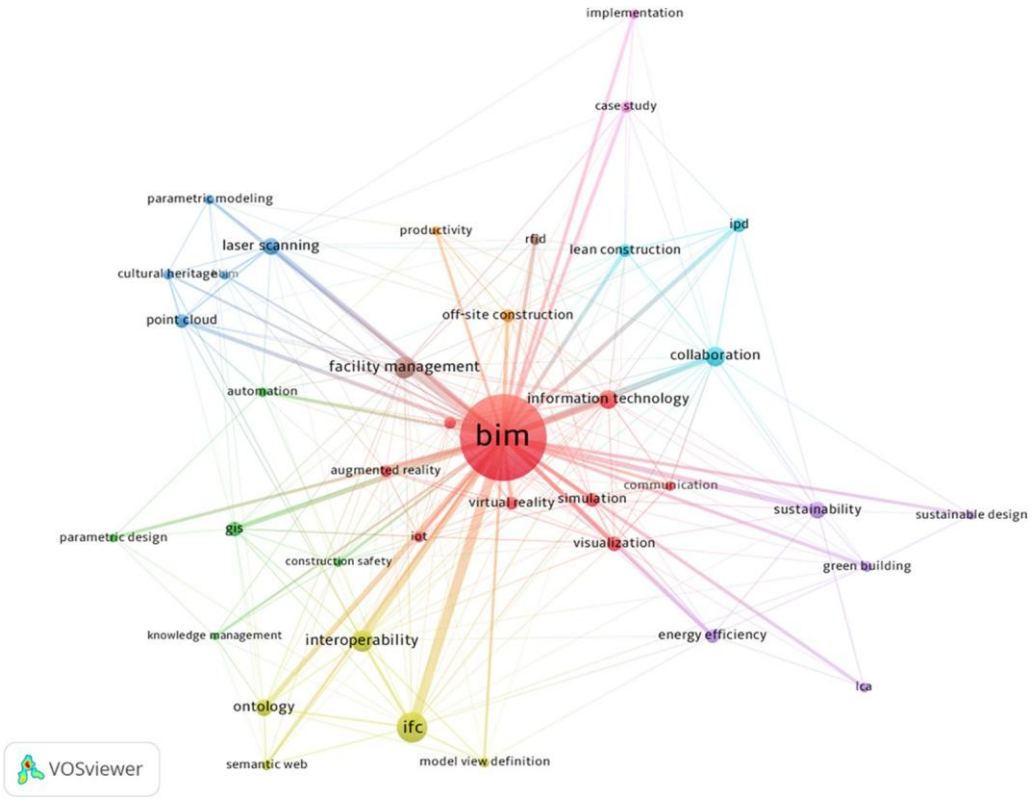

Fig. 3. Author keywords co-occurrence of BIM.

BIM for OSC

Interestingly, less attention has been directed toward BIM for OSC. Only 113 results were obtained for this research topic from the Scopus database, which is relatively fewer in comparison with BIM (4395) and OSC (2841) (see Table 2). In this section, 113 publications related to this topic were analyzed using a bibliometric approach, with the in- tention of exploring the current research patterns in BIM for OSC.

Co-occurrence analysis of author keywords. The keywords of 113 academic publications on BIM for OSC were fed into VOSviewer to generate a co-occurrence graph of author keywords. The minimum number of

time that a keyword must occur to be included was set to 3. Of the 220 keywords, 26 met the threshold. The cluster view of author keywords in the VOSviewer is shown in Fig. 5; the bigger the circle indicates the more times the item occurs in the literature [39]. The detailed quantity information for each of the keywords of BIM for OSC

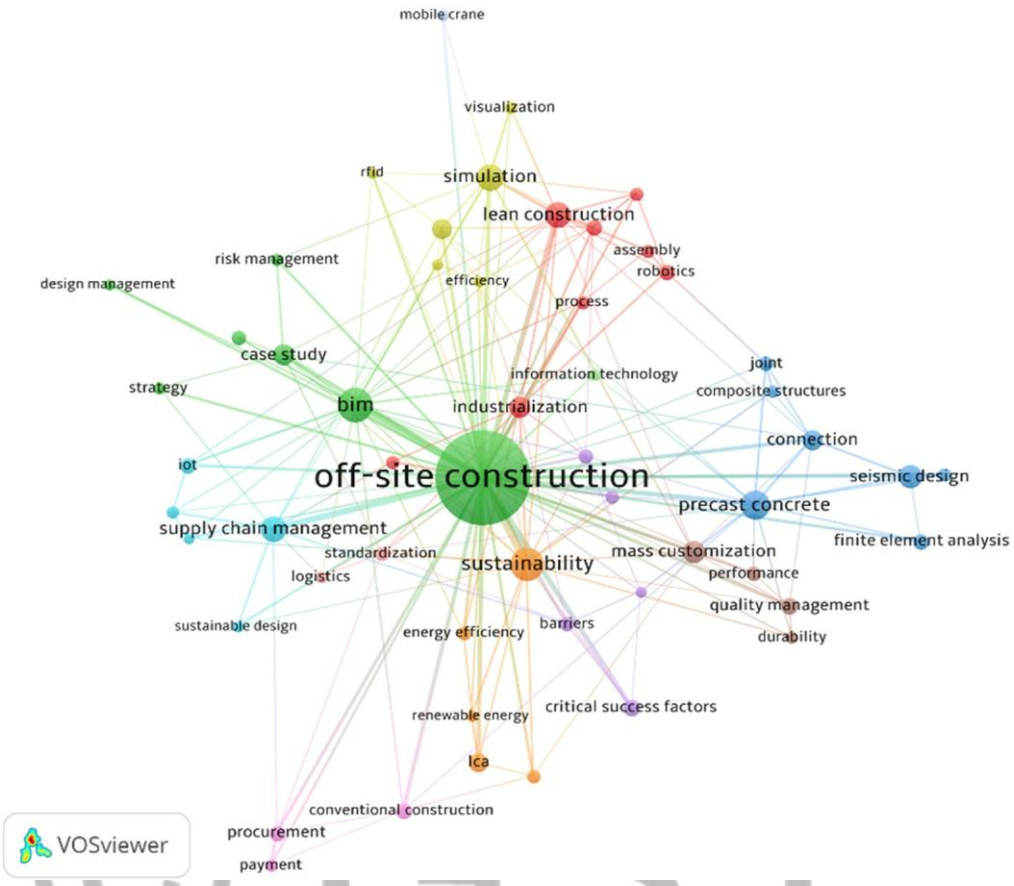

Fig. 4. Author keywords co-occurrence of OSC.

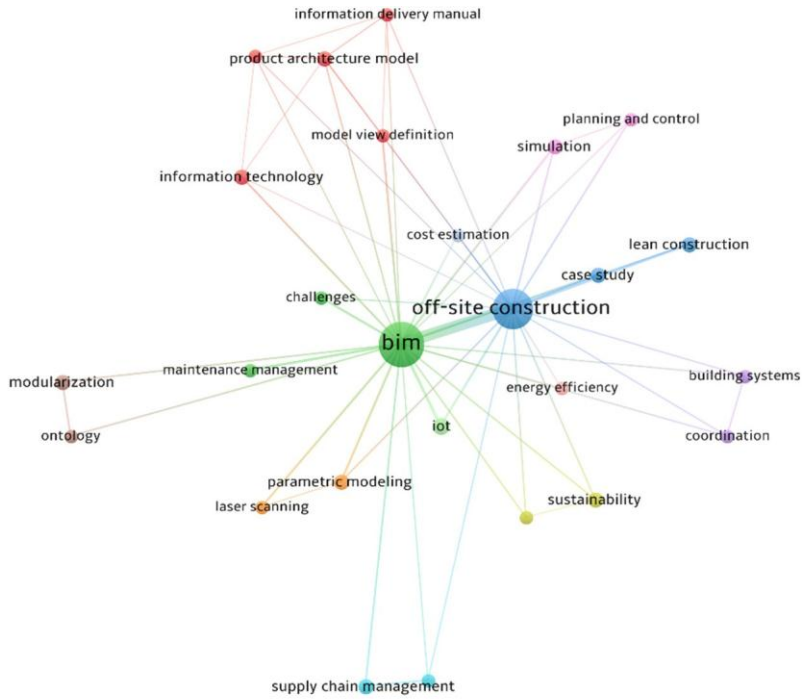

Fig. 5. Author keywords co-occurrence of BIM for OSC.

Conclusion

This study mainly investigates the current state-of-the-art of re- search regarding BIM for OSC. A mixed review was conducted to de- velop the science maps of BIM, OSC, and BIM for OSC and to provide deeper insights into the research gaps and needs with respect to BIM for OSC. In this research, a quantitative review is conducted using VOSviewer on the topic of BIM for OSC based on the literature retrieved from Scopus. Research focuses of existing academic articles were identified; they are spread over the whole life cycle of the OSC projects. In terms of BIM research, substantial existing studies focused on im- proving interoperability and data management, BIM for sustainability, BIM for facility management, integrating BIM with new technologies, and BIM collaboration and implementation. As for OSC research, the construction process managment, and product design and performance are two main topics in the existing literature. Research on BIM for OSC has shown an upward trend in recent years, especially after 2005.

Identified main research topics from bibliometric analysis are synthesized through a consensus discussion to develop a categorization structure. Then, categorization structure is used to guide qualitative review for in-depth discussions on research gaps and needs regarding BIM for OSC. By doing an in-depth qualitative analysis, several research directions are proposed. Potential research areas along with the re- search suggestions have also been proposed by authors, namely, BIM- based generative design for prefabrication, Cloud BIM-based data ex- change for OSC, robotics and 3D printing for OSC, BIM-enabled big data analytics toward best OSC practice, benefits and its assessment model of BIM for OSC.

References

[1] Cabinet Offi ce, H, Government construction strategy 2011, Construction, vol. 19, 2011.
[2] National BIM Standard – United States, National Building Information Model Standard Project Committee, 2018, Retrieved June 22, 2018, from, 2018. https:// www.nationalbimstandard.org/faqs.
[3] H. Liu, B. Holmwood, C. Sydora, G. Singh, M. Al-Hussein, Optimizing multi-wall panel configuration for panelized construction using BIM, The 9th International Structural Engineering and Construction Conference, 2017, pp. 1–6 Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027842859& partnerID=40&md5=035c8756724d5363de5e33d3175ef5a1.
[4] M. Farmer, The Farmer Review of the UK Construction Labour Model, Retrieved from, 2016. http://www.constructionleadershipcouncil.co.uk/wp-content/ uploads/2016/10/Farmer-Review.pdf.
[5] B. Becerik-Gerber, K. Kensek, Building information modeling in architecture, en- gineering, and construction: emerging research directions and trends, J. Prof. Issues Eng. Educ. Pract. 136 (3) (2010) 139–147, https://doi.org/10.1061/(ASCE) EI.1943-5541.0000023.
[6] T. Cerovsek, A review and outlook for a "building information model" (BIM): a multi-standpoint framework for technological development, Adv. Eng. Inform. 25 (2) (2011) 224–244, https://doi.org/10.1016/j.aei.2010.06.003.
[7] B. Soust-Verdaguer, C. Llatas, A. García-Martínez, Critical review of BIM-based LCA method to buildings, Energy Build. (2017), https://doi.org/10.1016/j.enbuild.2016.12.009.
[8] S. Eleftheriadis, D. Mumovic, P. Greening, Life cycle energy effi ciency in building structures: a review of current developments and future outlooks based on BIM capabilities, Renew. Sust. Energ. Rev. 67 (2017) 811–825, https://doi.org/10. 1016/j.rser.2016.09.028.
[9] E.A. Pärn, D.J. Edwards, M.C.P. Sing, The building information modelling tra- jectory in facilities management: a review, Autom. Constr. 75 (2017) 45–55, https://doi.org/10.1016/j.autcon.2016.12.003.
[10] A. Bradley, H. Li, R. Lark, S. Dunn, BIM for infrastructure: an overall review and constructor perspective, Autom. Constr. 71 (2016) 139–152, https://doi.org/10. 1016/j.autcon.2016.08.019.
[11] J. Wong, X. Wang, H. Li, G. Chan, H. Li, A review of cloud-based bim technology in the construction sector, J. Inf. Technol. Constr. 19 (2014) 281–291.
[12] P. Saieg, E.D. Sotelino, D. Nascimento, R.G.G. Caiado, Interactions of building information modeling, lean and sustainability on the architectural, engineering and construction industry: a systematic review, J. Clean. Prod. 174 (2018) 788–806,

https://doi.org/10.1016/j.jclepro.2017.11.030.
[13] Y. Lu, Z. Wu, R. Chang, Y. Li, Building information modeling (BIM) for green buildings: a critical review and future directions, Autom. Constr. 83 (2017) 134–148, https://doi.org/10.1016/j.autcon.2017.08.024.
[14] M.F. Antwi-Afari, H. Li, E.A. Pärn, D.J. Edwards, Critical success factors for im- plementing building information modelling (BIM): a longitudinal review, Autom. Constr. 91 (2018) 100–110, https://doi.org/10.1016/j.autcon.2018.03.010.
[15] L. Ding, Y. Zhou, B. Akinci, Building information modeling (BIM) application framework: the process of expanding from 3D to computable nD, Autom. Constr. 46 (2014) 82–93, https://doi.org/10.1016/j.autcon.2014.04.009.
[16] B. Succar, Building information modelling framework: a research and delivery foundation for industry stakeholders, Autom. Constr. 18 (3) (2009) 357–375, https://doi.org/10.1016/j.autcon.2008.10.003.
[17] V. Singh, N. Gu, X. Wang, A theoretical framework of a BIM-based multi-dis- ciplinary collaboration platform, Autom. Constr. 20 (2) (2011) 134–144, https:// doi.org/10.1016/j.autcon.2010.09.011.
[18] M. Yalcinkaya, V. Singh, Patterns and trends in Building Information Modeling (BIM) research: a latent semantic analysis, Autom. Constr. 59 (2015) 68–80, https://doi.org/10.1016/j.autcon.2015.07.012.
[19] C.Z. Li, R.Y. Zhong, F. Xue, G. Xu, K. Chen, G.G. Huang, G.Q. Shen, Integrating RFID and BIM technologies for mitigating risks and improving schedule perfor- mance of prefabricated house construction, J. Clean. Prod. 165 (2017) 1048–1062, https://doi.org/10.1016/j.jclepro.2017.07.156.
[20] X. Li, Z. Li, G. Wu, Modular and off site construction of piping: current barriers and route, Appl. Sci. 7 (6) (2017) 547, https://doi.org/10.3390/app7060547.
[21] X. Li, P. Wu, G.Q. Shen, X. Wang, Y. Teng, Mapping the knowledge domains of Building Information Modeling (BIM): a bibliometric approach, Autom. Constr. 84 (2017) 195–206, https://doi.org/10.1016/j.autcon.2017.09.011.
[22] R. Santos, A.A. Costa, A. Grilo, Bibliometric analysis and review of building in- formation modelling literature published between 2005 and 2015, Autom. Constr. 80 (2017) 118–136, https://doi.org/10.1016/j.autcon.2017.03.005.
[23] M. Oraee, M.R. Hosseini, E. Papadonikolaki, R. Palliyaguru, M. Arashpour, Collaboration in BIM-based construction networks: a bibliometric-qualitative lit- erature review, Int. J. Proj. Manag. 35 (7) (2017) 1288–1301, https://doi.org/10. 1016/j.ijproman.2017.07.001.
[24] 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 (4) (2017) 670–685, https://doi.org/10.1016/j.ijproman.2016.08.001.
[25] X. Zhao, A scientometric review of global BIM research: analysis and visualization, Autom. Constr. 80 (2017) 37–47, https://doi.org/10.1016/j.autcon.2017.04.002.
[26] M.R. Hosseini, M. Asce, M. Maghrebi, A. Akbarnezhad, I. Martek, M. Arashpour, Analysis of citation networks in building information modeling research, J. Constr. Eng. Manag. 144 (8) (2018) 04018064, , https://doi.org/10.1061/(ASCE)CO. 1943-7862.0001492.
[27] 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, https://doi.org/10.1016/j.autcon.2017.12. 002.
[28] M. Kamali, K. Hewage, Life cycle performance of modular buildings: a critical review, Renew. Sust. Energ. Rev. 62 (2016) 1171–1183, https://doi.org/10.1016/ j.rser.2016.05.031.
[29] Z. Li, G.Q. Shen, X. Xue, Critical review of the research on the management of prefabricated construction, Habitat Int. 43 (2014) 240–249, https://doi.org/10. 1016/j.habitatint.2014.04.001.
[30] S. Mostafa, N. Chileshe, T. Abdelhamid, Lean and agile integration within off site construction using discrete event simulation a systematic literature review, Constr. Innov. 16 (4) (2016) 483–525, https://doi.org/10.1108/CI-09-2014-0043.
[31] F.H. Abanda, J.H.M. Tah, F.K.T. Cheung, BIM in off -site manufacturing for buildings, J. Build. Eng. 14 (2017) 89–102, https://doi.org/10.1016/j.jobe.2017. 10.002.
[32] K. Chen, W. Lu, Y. Peng, S. Rowlinson, G.Q. Huang, Bridging BIM and building: from a literature review to an integrated conceptual framework, Int. J. Proj. Manag. 33 (6) (2015) 1405–1416, https://doi.org/10.1016/j.ijproman.2015.03. 006.
[33] A. Harden, J. Thomas, Mixed methods and systematic reviews: examples and emerging issues, SAGE Handbook of Mixed Methods in Social & Behavioral Research, 2010, pp. 749–774, , https://doi.org/10.4135/9781506335193.
[34] P.X.W. Zou, R.Y. Sunindijo, A.R.J. Dainty, A mixed methods research design for bridging the gap between research and practice in construction safety, Saf. Sci. (2014), https://doi.org/10.1016/j.ssci.2014.07.005.
[35] R.B. Johnson, A.J. Onwuegbuzie, Mixed methods research: a research paradigm whose time has come, Educ. Res. (2004), https://doi.org/10.3102/0013189X033007014.
[36] J.C. Greene, V.J. Caracelli, W.F. Graham, Toward a conceptual framework for mixed-method evaluation designs, Educ. Evavl. Policy Anal. 11 (3) (1989) 255–274, https://doi.org/10.3102/01623737011003255.
[37] M. Oraee, M.R. Hosseini, E. Papadonikolaki, R. Palliyaguru, M. Arashpour, Collaboration in BIM-based construction networks: a bibliometric-qualitative lit- erature review, Int. J. Proj. Manag. 35 (7) (2017) 1288–1301, https://doi.org/10. 1016/J.IJPROMAN.2017.07.001.
[38] M.J. Cobo, A.G. López-Herrera, E. Herrera-Viedma, F. Herrera, Science mapping software tools: review, analysis, and cooperative study among tools, J. Am. Soc. Inf. Sci. Technol. 62 (7) (2011) 1382–1402, https://doi.org/10.1002/asi.
[39] N.J. van Eck, L. Waltman, Software survey: VOSviewer, a computer program for bibliometric mapping, Scientometrics 84 (2) (2010) 523–538, https://doi.org/10. 1007/s11192-009-0146-3.
[40] A. Booth, A. Sutton, D. Papaioannou, Systematic Approaches to a Successful Literature Review, Sage, 2016.
[41] M.D. Martínez-Aires, M. López-Alonso, M. Martínez-Rojas, Building information modeling and safety management: a systematic review, Saf. Sci. 101 (2018) 11–18, https://doi.org/10.1016/j.ssci.2017.08.015.
[42] N.J. Van Eck, L. Waltman, Cnpq Capes, Icict Faperj, VOSviewer: a computer program for bibliometric mapping, 12th International Conference on Scientometrics and Informetrics, 2009, pp. 886–897.
[43] C. Chen, F. Ibekwe-SanJuan, J. Hou, The structure and dynamics of cocitation clusters: a multiple-perspective cocitation analysis, J. Am. Soc. Inf. Sci. Technol. 61 (7) (2010) 1386–1409, https://doi.org/10.1002/asi.21309.
[44] N.J. van Eck, L. Waltman, CitNetExplorer: a new software tool for analyzing and visualizing citation networks, J. Inf. 8 (4) (2014) 802–823, https://doi.org/10. 1016/j.joi.2014.07.006.
[45] P. Mongeon, A. Paul-Hus, The journal coverage of web of science and Scopus: a comparative analysis, Scientometrics (2016), https://doi.org/10.1007/s11192- 015-1765-5.
[46] Iowa State University Library, Scopus: Comparisons, Retrieved November 27, 2018, from, 2018. http://instr.iastate.libguides.com/c.php?g=120420&p= 785310.
[47] X. Cao, X. Li, Y. Zhu, Z. Zhang, A comparative study of environmental performance between prefabricated and traditional residential buildings in China, J. Clean. Prod. 109 (2015) 131–143, https://doi.org/10.1016/j.jclepro.2015.04.120.
[48] C. Mao, Q. Shen, W. Pan, K. Ye, Major barriers to off -site construction: the de- veloper's perspective in China, J. Manag. Eng. 31 (3) (2015) 04014043, , https:// doi.org/10.1061/(ASCE)ME.1943-5479.0000246.
[49] A. Perianes-Rodriguez, L. Waltman, N.J. van Eck, Constructing bibliometric net- works: a comparison between full and fractional counting, J. Inf. 10 (4) (2016) 1178–1195, https://doi.org/10.1016/j.joi.2016.10.006.
[50] P.C. Lee, H.N.N. Su, Investigating the structure of regional innovation system re- search through keyword co-occurrence and social network analysis, Innov. Manag. Policy Pract. (2010), https://doi.org/10.5172/impp.12.1.26.