Building information modeling (BIM) in project management: A bibliometric and science mapping review

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Abstract:	

Building information modeling (BIM) in project management: A bibliometric and science mapping review

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Abstract

Purpose – The impact of building information modeling (BIM) on various aspects of project management has attracted much attention in the past decade. However, previous studies have focused on a particular facet of project management (e.g., safety, quality, facility management) and within identified target journals. Despite numerous existing studies, there is limited research on the mainstream research topics, gaps, and future research directions on BIM in project management. This study aims to conduct a bibliometric and science mapping review of published articles on BIM in project management and to identify mainstream research topics, research gaps, and future research directions in this domain.

Design/methodology/approach – A science mapping approach consisting of bibliometric search, scientometric analysis, and qualitative discussion was used to analyze 521 journal articles that were retrieved from the Scopus database and related to BIM in project management. In the scientometric analysis, keyword co-occurrence analysis and document analysis were performed. This was followed by a qualitative discussion that seeks to propose a framework summarizing the interconnection between the mainstream research topics, research gaps, and future research directions.

Findings – Six mainstream research topics were found including (1) BIM-enabled advanced digital technologies, (2) BIM-based reinforcement and enhancement, (3) BIM and project composition, (4) BIM project elements and attributes, (5) BIM-based collaboration and communication, and (6) BIM-based information and data. Moreover, this study discussed six research gaps, namely (1) integration of BIM and other digital technologies, (2) future maturity of BIM applications in project management, (3) application of BIM in project components and processes, (4) role of BIM application in project elements and attributes, (5) impact of collaboration and communication in BIM application, and (6) stability of information and data interaction. Furthermore, future research directions were discussed.

Originality – The findings and proposed framework contribute to providing a deeper understanding to researchers, policymakers, and practitioners in the development of related research and practice in the domain of BIM in project management, thus, promoting digital transformation in project management. Overall, it adds to the global knowledge domain in BIM

and promotes the need for digital and data integration, BIM maturity, and BIM collaboration.
Keywords: Bibliometric analysis; Building information modeling (BIM); Project management; Science mapping; Scientometric review
Paper type: Literature review

1. Introduction

Digital transformation has gradually penetrated various sectors in recent decades as technology has evolved and people's needs for products and services have changed (Nagy *et al.*, 2018). Specifically, building information modelling (BIM) has had a profound impact on the architecture, engineering, and construction (AEC) sector (Celoza *et al.,* 2023). According to McGraw-Hill Construction (2012), 70 percent of contractors in North America are using BIM. The United Kingdom government in its comprehensive construction strategy (Maude, 2011) mentioned the benefits of BIM and mandated a target of 2016 for publicly procured projects. Consequently, the applications of BIM in different sectors have yielded many benefits in several countries.

Research on BIM has also flourished in the past decade (Zhang *et al.*, 2013; Belay *et al.,* 2021; Tang *et al.,* 2021; Chen *et al.,* 2023; Moshtaghian and Noorzai, 2023; Zhang *et al.,* 2023). Ma *et al.* (2020) and Belay *et al.* (2021) have studied the strategies and drivers of BIM implementation. Zhang *et al.* (2013) and Tang *et al.* (2021) have discussed the role of BIM in construction and building safety. In addition, Lin *et al.* (2022) envisaged the use of BIM in construction and facilities management (FM). Since BIM has extensively been studied in project management, a state-of-the-art review of various aspects of BIM in project management can help identify the mainstream research areas and contribute to identifying key research gaps and future directions.

Several review articles have reported on the various aspects of BIM applications (Wong and Zhou, 2015; Antwi-Afari *et al.,* 2018; Kamel and Memari, 2019; Potrč Obrecht *et al.,* 2020; Wu *et al.,* 2022). Potrč Obrecht *et al.* (2020) explored BIM applications and the challenges of lifecycle assessment in building design. Wong and Zhou (2015) reviewed research on BIM and building sustainability. Kamel and Memari (2019) also reviewed articles on BIM and energy simulation. The aforementioned review articles summarized the extant literature in a specific area of BIM in project management, and they contribute to the body of knowledge in their respective areas of research. However, none of the previous reviews has thoroughly examined and systematically reviewed the state-of-the-art BIM in project management in its entirety. Many other previous review studies on BIM are limited to specific concepts in project management (He *et al.,* 2017; Li *et al.,* 2017; Lu *et al.,* 2017; Chan *et al.,* 2018; Martínez-Aires *et al.,* 2018; Sanhudo *et al.,* 2018; Akram *et al.,* 2019; Farzaneh *et al.,* 2019; Matarneh *et al.,* 2019; Saka and Chan, 2019; Santos *et al.,* 2019; Ivson *et al.,* 2020). For example, He *et al.* (2017) summarized the managerial areas of BIM and provided a conceptual framework encompassing current and future directions after reviewing 126 literature samples published between 2007 and 2015. Martínez-Aires *et al.* (2018) reviewed the relevant literature and concluded that BIM can change the way safety issues are handled in the AEC industry by identifying and preventing potential safety hazards in an effective and automated manner. Ivson *et al.* (2020) conducted a systematic review of BIM visualization within the visualization community, finding the synergies between scientific and information visualization to integrate spatial and non-spatial data. By using a structured approach, Chan *et al.* (2018) conducted a review of BIM in project management from 2005 to 2017 within identified target journals. Despite the reported findings on BIM in project management, the adopted method was limited to articles identified in target journals according to Chau's ranking (Wing, 1997). Collectively, these review articles addressed the application of BIM in specific aspects of project management, but not from a more macro perspective, i.e., integrating the broad category of project management. In contrast to previous review studies, which focused on specific aspects of BIM in project management (e.g., safety, quality, facility, and lean management), this study extends the scope to all aspects of project management. As such, there is still a missing research gap in reviewing articles related to broader areas of BIM in project management through quantitative analysis and mapping of large bibliometric datasets. Moreover, none of the existing review studies utilized a science mapping approach to analyze BIM in project management research to identify mainstream research topics, research gaps, and potential research directions for future studies.

In this review study, the overarching research question is "what are the mainstream research topics, research gaps, and future research directions regarding the application of BIM in project management". To fill these research gaps, this study aims to conduct a science mapping-based review of the extant literature on BIM in project management and to discuss the mainstream research topics, research gaps, and future research directions. To achieve the overarching research aim, the specific research objectives of this study are to:

1) Analyze the annual publication trend and peer-reviewed journals on BIM in project management.
2) Conduct a science mapping analysis based on the co-occurrence of keywords and document analysis.
3) Discuss the mainstream research topics on BIM in project management.
4) Highlight the research gaps and future research directions on BIM in project management.

The results of this review study could help researchers, policymakers, and practitioners to better understand the current state and future needs of BIM to promote research towards digital transformation in project management. Specifically, the findings would help researchers not only pay attention to the less explored areas of BIM in project management, but they would also explore the integration of BIM and other digital innovations (e.g., robotics, blockchain, virtual reality) to solve research problems in project management. In addition, the findings would provide practical understanding to practitioners on the maturity of BIM applications and their impact on building components and processes. The remainder of this review is as follows. Section 2 presents the research methodology adopted in this review study. Section 3 highlights the results of this review study. The discussions on mainstream research topics, research gaps, and future research directions are elaborated in Section 4. Lastly, the conclusions are presented in Section 5.

2. Research methodology

This study used the science mapping approach to review related research articles on BIM in project management. Science mapping is a generic process of domain analysis and visualization (Chen, 2017). It aims at the spatial representation of how disciplines, fields, and authors are related to one another within a body of literature (Small, 1999). The science mapping approach measures the impact of research while also analyzing institutional and peer-reviewed journals and gives researchers using the method a deeper understanding of the scientific knowledge and citations of the research content (Antwi-Afari *et al.,* 2023; Sun *et al.,* 2023). It includes three steps: bibliometric search, scientometric analysis, and qualitative discussion (Shi and Antwi-Afari, 2023). A detailed overview of the research methodology is shown in Fig. 1.

<Please insert Figure 1 about here>

2.1. Bibliometric search

The articles analyzed in this review study were retrieved from the Scopus database because of its extensive collection of related research in the AEC sector (Mongeon and Paul-Hus, 2015). Bibliometric search can present the structural dynamics of a scientific field through quantitative analysis and mapping of large bibliometric datasets. As such, bibliometric analysis can help to reveal the development process of a scientific discipline and provide insight into emerging areas of the field. It is useful for identifying new research trends, collaboration networks, research topics, and for investigating the structure of knowledge in a scientific field (Shi and Antwi-Afari, 2023).

Initially, a search was conducted in the Scopus database using keywords such as "building information modeling" and "project management" in the "title, abstract, and keywords" section. It yielded a total of 4,215 results. The studied period was limited to articles published from 2011 to 2023 (as of 6 October 2023), excluding articles prior to this period. This is because there were fewer articles in the Scopus database using these two main keywords before 2011, and BIM was not widely studied yet before that time. Since 2011, the number of BIM-related studies published each year has increased considerably, far more than before (Santos *et al.,* 2019), and literature on BIM in project management from 2011 to 2023 (years inclusive) represents a significant proportion of all relevant studies. After this step, the number of articles was reduced to 3,713. Next, 2,747 results were obtained by excluding those articles not related to the two subject areas of "engineering" and "business, management, and accounting". This is because these subject areas (i.e., engineering and business, management, and accounting) are the primary disciplines in project management. Afterwards, the document type was limited to "article", excluding articles in press in the publication stage. Moreover, articles were excluded other than those in "journal" whilst keeping only articles written in English. After these steps, 1,205 results were retrieved.

To minimize potential bias during the screening process, two independent reviewers (ZY and MA) conducted the search strategies and resolved any queries. To ensure the quality of articles used for further analyses, journal sources other than quartiles 1 and 2 (according to journal citation report in Web of Science) were excluded. Quartiles 1 and 2 journals are widely recognized by scholars and are often seen as a more reputable source, or even as certified knowledge (Ramos-Rodríguez and Ruíz-Navarro, 2004), and it has also been argued that articles originating from Quartiles 1 and 2 journals tend to be more comprehensive (Zheng *et al.,* 2016). In addition, the selected quartiles 1 and 2 journals must have 5 or more published articles during the studied period. After the screening steps, 638 articles were obtained. Given that the retrieved articles may still not meet the eligibility of this study, further manual screening was carried out by reading the abstracts and full texts. Articles that are not aligned with the research scope of BIM in project management were excluded. For instance, existing review articles (e.g., Oraee *et al.,* 2017; Wu *et al.,* 2022) were excluded. Moreover, a study by Malhotra *et al.* (2022) on modeling the heating demand of urban buildings was excluded because the full text does not relate to BIM. Manual screening of articles may contribute to the validity of the results by ensuring that the included articles reflect the scope of the studied topic. After manual screening, 521 articles were obtained and used for further analyses. Table 1 shows the search strings and literature search results in Scopus.

<Please insert Table 1 about here>

2.2. Scientometric analysis

The second step is scientometric analysis, an analytical approach often used to evaluate the development of scientific disciplines, authorship patterns, and generation of scientific knowledge (van Eck and Waltman, 2009). VOSviewer was used in this step to analyze the literature and visualize network maps. It is a scientific mapping tool for creating and presenting network maps (van Eck and Waltman, 2009). It is widely applied by many scholars in review-related studies because of its usefulness and accessibility. For example, VOSviewer was used in a review study conducted on construction safety (Jin *et al.,* 2019), blockchain technology (Sun *et al.*, 2023), and work-related musculoskeletal disorders (Antwi-Afari *et al.,* 2023). Compared to other scientific mapping tools such as BibExcel, CiteSpace, CoPalRed, Gephi, IN-SPIRE, Science of Science tools, etc., VOSviewer is not only very easy to understand and operate, but also offers free visualization capabilities (Antwi-Afari *et al.,* 2023). Therefore, this review study adopted VOSviewer to create and visualize network maps of BIM in project management articles to conduct: (1) keyword co-occurrence analysis, and (2) document analysis. Keyword co-occurrence analysis evaluates the number of documents associated with an emerging keyword whilst document analysis shows the number of documents published by a source, an author, an institution, or a country/region (van Eck and Waltman, 2009).

2.3. Qualitative discussion

In the qualitative discussion, this review study discussed the mainstream research topics of BIM in project management based on the keywords and articles analyzed in the previous steps. It also presents a framework of research gaps and potential research directions that deserve more attention in the domain of BIM in project management.

3. Results

This section presents the results of the bibliometric and scientometric analyses. Sections 3.1 and 3.2 addressed the first research objective on the annual publication trend and peer-reviewed journals on BIM in project management. The second research objective was addressed in sections 3.3 and 3.4 based on keyword co-occurrence analysis and document analysis, respectively. Collectively, these results informed the qualitative discussion in section 4 regarding the mainstream research topics, research gaps, and future research directions on BIM in project management.

3.1. Annual publication trend of articles

The annual publication trend of 521 articles identified from the Scopus database is summarized in Fig. 2. It clearly shows a significant overall upward trend in the number of articles related to BIM in project management from 2011 to 2023. These annual increases in the number of publications reflect the overall interest and contribution of researchers and practitioners, particularly on BIM in project management (Ma *et al.,* 2020; Belay *et al.,* 2021; Zhang *et al.,* 2013; Lin *et al.,* 2022). In addition, the increase could be due to several government mandates that required the use of BIM on public projects (e.g., the UK government mandated that all central government projects should use BIM by 2016). Although the data for 2023 only ends on 6th October, it has already reached 50 articles, so it is reasonable to assume that there won't be a significant decrease in the number of relevant articles throughout 2023. As indicated in Figure 2, the overall trend of research related to BIM in project management increases yearly, with a higher number of publications recorded in 2021. However, the number of articles in 2020 and 2021 also shows that the exploration of the studied topic has not been affected by the impact of Covid-19. The number of annual publications for 2023 could not be confirmed at the time of the literature search, hence, subsequent future studies would be required to confirm whether this speculation is correct.

<Please insert Figure 2 about here>

3.2. Selection of peer-reviewed journals

In addition to the annual publication trends for the 521 included articles, the journals in which these articles had been published were also summarized, and detailed results are presented in Table 2. Table 2 shows the selected peer-reviewed journals, number of publications, and percentage of total publications. It is chronologically arranged in order of number of published articles in a journal outlet.

Table 2 clearly shows that nearly 19% of the articles are published in *Automation in Construction.* It is followed by *Engineering, Construction and Architectural Management* and *Buildings* with percentage of total publications of 9.79% and 8.64%, respectively. The number of articles published in *Journal of Construction Engineering and Management* also accounts for around 8% of the total articles. *Safety Science* reported the least number of published articles, with two articles accounting for 0.38% of the total number of articles. It was found that *Automation in Construction* is a journal that has been influential in research publications related to BIM in project management (Table 2). Instead, *Building and Environment, Journal of Cleaner Production, Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, and Safety Science,* all accounted for less than 0.8% of each of the total articles, indicating less active in this area of research publication. Overall, the selected peer-reviewed journals can serve as a guide for other researchers and practitioners in ascertaining suitable outlets within which to disseminate their research.

<Please insert Table 2 about here>

3.3 Keyword co-occurrence analysis

The co-occurrence analysis of keywords can help to improve the understanding of articles on the same topic. Keywords often reflect the main content of a study and the domain of the topic whilst author keywords play an important role in information retrieval, co-word analysis, and mainstream topics (Su and Lee, 2010). According to Perianes-Rodriguez *et al.* (2016), fractional counting provides a more useful perspective and is less likely to lead to misinterpretation than full counting, making it preferable for most studies. For this reason, keyword co-occurrence analysis was carried out in VOSviewer by selecting "author keywords" and "fractional counting" and setting the minimum number of occurrences of a keyword to 6, resulting in 43 out of 1,614 keywords. Some keywords that recurred with the same meaning, but different expressions were deleted. For example, "building information modeling" was repeated as a keyword in different expressions such as "BIM" and "building information modeling (BIM)". Of these different expressions, only the one with the most occurrence was retained. In addition, if two keywords with the same meaning appear in both singular and plural forms, such as "facility management" and "facilities management", the one with less occurrence was deleted. After these steps, a visualization network was generated from 35 keywords as shown in Fig. 3.

Keywords such as "BIM", "construction management", and "project management", as shown in Fig. 3, are frequently mentioned in existing research on BIM in project management. The connecting lines in Fig. 3 show the interconnectedness of the two keywords. For example, "BIM" is closely linked to "construction management", indicating BIM is often used in construction management. Since project management includes information management and BIM can be very beneficial to project management, there are connecting lines linking "BIM", "project management", and "information management" (Wijekoon *et al.,* 2018).

The keywords in Fig. 3 are also grouped into six clusters, with keywords within each cluster being explored together in the same article. For example, facility management is often explored together with collaboration, as mentioned in El Ammari and Hammad (2019)'s study. They are often associated with simulation, so they are all classified in the same cluster. The font sizes in Fig. 3 reflect the frequency/occurrence of keywords studied in the selected articles. However, keywords with low frequency cannot be seen in Fig. 3. As such, Table 3 shows the quantitative summary of keyword co-occurrence analysis on BIM in project management. It presents the number of occurrences, average publication year, average citations, and average normalized citation for each keyword. The keywords in Table 3 were chronologically arranged based on the average normalized citations.

It was found that the number of occurrences is not necessarily positively correlated with the average citations and average normalized citations (Table 3). For example, "case study" has more occurrences than "construction safety", but its average citations and average normalized citations are significantly lower. The keywords with the highest average normalized citations are "digital twin", "blockchain" and "barriers", which reflect the importance of BIM and digital twin applications in projects (Pan and Zhang, 2021). Many studies also focused on the use of BIM in blockchain management (Li *et al.,* 2022), and some scholars are interested in the combined application of BIM and ontology in projects (Ren *et al.,* 2021). The average publication year shows the latest level of research and keywords in the selected articles. From Table 3, most of the keywords in the average publication year are within the last 5 years of the studied period. "Blockchain" had the most recent average publication year (i.e., 2022), indicating its relatively new research domain on BIM in project management.

<Please insert Figure 3 about here>

<Please insert Table 3 about here>

3.4. Document analysis

In VOSviewer, "citation" and "documents" were selected, and the minimum number of citations of a document was set to 89, resulting in 44 articles out of 521. The network visualization of document citation analysis is shown in Fig. 4.

It is presented in Fig. 4 that there are some interactions between most of the articles while other articles showed a stray status, possibly with a weak citation relationship to the selected articles, such as Zhang and El-gohary (2017) and Golparvar-fard *et al.* (2011). The size of the nodes represents the number of citations of an article. A study by Bryde *et al.* (2013) had the largest node, showing its significant number of citations. Eadie *et al.* (2013) had the second largest node and belongs to the green cluster. The above results inferred that these articles received the highest number of citations. Articles within the same cluster tend to be more deeply connected and influenced by each other, and the connection lines between the nodes indicate citation relationships. For example, Chen *et al.* (2014)'s study is connected to several articles such as Park *et al.* (2013) and Love *et al.* (2014).

Table 4 presents a detailed breakdown of the contribution and influence of each article related to BIM in project management. It was sorted in chronological order of normalized citations. Due to the purpose of presentation, Table 4 only listed the top ten articles in order of highest normalized citations, but it also shows the highest total citations. Of the articles not listed in Table 4, Elghaish *et al.* (2020) and Chan *et al.* (2019) also have normalized citations of 3.74 and 3.71, respectively. The article with the highest normalized citations was Pan and Zhang (2021), which focused on building a closed-loop digital twin framework through the collaborative use of BIM, internet of things (IoTs), and data mining. Besides, the article with the highest total citations, i.e., Bryde *et al.* (2013) explored the extent to which the use of BIM can be beneficial in projects.

Most of the articles in Table 4 focused on specific applications of BIM in different aspects of project management, such as FM (Pishdad-bozorgi *et al.,* 2018), construction safety (Zhang *et al.,* 2015), etc. Besides, other existing studies focused on different BIM applications and discussed how BIM could be integrated with other technologies (e.g., Li *et al.,* 2018; Pour Rahimian *et al.,* 2020). Whilst some existing studies focused on various practical BIM applications, other articles are more theoretical in nature such as the project benefits of BIM (Bryde *et al.,* 2013).

<Please insert Figure 4 about here>

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4. Discussion

4.1. Mainstream research topics

4.1.1. BIM-enabled advanced digital technologies

Given that digital technologies involve several advanced information approaches, the included articles explored their impacts on BIM and project management from a macro perspective. May *et al.* (2022) developed a BIM-based on-site augmented reality (AR) defect management (BIM-ARDM) system, which showed how it outperformed conventional models in terms of usability, workload, performance, completion time, detecting building elements, identifying flaws, and helping people with inspection chores. Çıdık *et al.* (2017) revealed the phenomenon of continuous change at the practice level driven by digital integration in BIM-enabled projects. Jaradat *et al.* (2013) explored the impact of digital systems and media, including BIM, on different occupations, groups, and roles in projects. Comparatively, Sezer and Bröchner (2019) investigated information and communications technology (ICT) preferences of site managers in terms of resource usage on refurbishment projects to aid the development of digital supports such as BIM and ICT. Pan and Zhang (2021) developed a digital twin framework to enhance project management through the integration of BIM, IoT, and data mining. According to their research, the digital twin framework, built as part of the BIM foundation, can help with the communication and exploration of data and the optimization of physical structures in a project. Daniotti *et al.* (2022) used BIM as a basis for a framework and toolkit for building renovation projects. Their study focused on the use of BIM and digital twins for managing information and working time in building renovation projects and further explored its impact on improving building performance, quality, and occupants' comfort. Overall, extant studies related to this research topic mainly focused on integrating different digital technologies with BIM to facilitate the successful delivery of projects (Hsu *et al.*, 2023; Panya *et al.*, 2023; Tao *et al.*, 2023). As technology develops and innovations emerge, several advanced digital technologies will be integrated with BIM. Although the integration of advanced digital technologies and BIM can bring numerous benefits to researchers, project managers, and other practitioners, it may require resource capabilities and training which may lead to increased project cost and data storage.

4.1.2. BIM-based reinforcement and enhancement

BIM may have issues when applied to practical projects. There are many barriers to the practical application of BIM, perhaps brought about by BIM itself, or due to external factors such as the characteristics of a project, personnel, policy, and industry (Liu *et al.,* 2022; Tian *et al.,* 2023; Zhang *et al.,* 2023). BIM was found to have key barriers such as training cost, BIM software cost, insufficient knowledge, and lack of adequate BIM guidelines in the application of AEC industry projects (Hyarat *et al.,* 2022). In addition, BIM barriers have an impact on BIM awareness in the project cycle, and they include cost and standards, process and economics, technology and business, training, and people (Olanrewaju *et al.,* 2022). Given the above, the prevalence of cost, technical knowledge, and training were the main barriers to BIM adoption. Notably, research studies on the barriers to BIM adoption also suggested ways of improvement and the spread of BIM adoption. Sanhudo *et al.* (2020) proposed a framework to improve the lack of standards and legislation for BIM in energy-related projects and evaluated the applicability of the framework through case studies. The impact of the level of development (LOD) in the application of BIM was investigated in several case studies, finding further identification of challenges and solutions (Alshorafa and Ergen, 2019). The above-mentioned articles are generally oriented towards the reinforcement and progress of BIM, which would help to promote the future maturity of BIM and enhance its usage in real-world projects.

4.1.3. BIM and project composition

Many scholarly articles have demonstrated the impact of BIM on specific components or processes within a project, finding diverse pathways in different project processes. Simulation is the use of software to run a mock-up of a project's plans or ideas, usually prior to the actual construction of the project or some important procedures in the project (Arora, 2007). With the introduction of BIM into project management, many simulation works are influenced by BIM. The use of a hybrid approach, including BIM, to simulate all possible space-time conflicts in a project can provide an effective preventive measure against space-time conflicts and significantly reduce their negative impact on the project (Dashti *et al.,* 2021). Heavy industrial construction projects often require multiple cranes to be used simultaneously, and upfront simulation and planning are essential to avoid accidents. Tak *et al.* (2021) proposed a BIM-based five-component framework to generate accurate operation plans at micro and macro scales, which is beneficial for managing dynamic multi-crane operations. Jang and Lee (2018) analyzed the processes, productivity, and economic benefits of BIM-based multi-trade prefabrication. They found that system coordination, parallel execution of work, and changes in man-hours due to activities lead to various contradictory perceptions of the benefits of BIM for multi-trade fabrication. Existing studies on the role and impact of BIM in the different components and processes of a project provide a clearer representation of the specific applications of BIM (de Souza *et al.,* 2023; Marzouk and Thabet, 2023). This would help in the advanced application of BIM in detailed components of a project for future studies.

4.1.4. BIM project elements and attributes

The articles in this section briefly discuss three broad topics including the impact of BIM on construction safety, quality management, and environmental protection/sustainability in projects. BIM can assist in construction site planning to improve safety in a crowded and dynamic site environment (Zhang *et al*., 2015b; Chen *et al.,* 2023). By using remote sensing and BIM techniques, Zhang *et al.* (2015b) created automated workspace visualization based on global positioning systems (GPS) and movable facilities. In addition to considering construction site activities in terms of staff and facilities, construction safety can also be aided by observing and modeling the site geospatially. BIM also has a role to play in quality management of projects, and there has been considerable research into design quality management (Faraji *et al.,* 2022; Kim *et al.,* 2022; Koo and O'Connor, 2022). Koo and O'Connor (2022) analyzed 160 indicators of design defects to determine the role of BIM as a driver of design quality and further suggested areas where BIM still needs to be improved in terms of design quality. The use of BIM with unmanned aerial vehicle (UAV) technology can assist in resolving quality issues that may arise during the design phase, which contributes to customer satisfaction and design quality management (Faraji *et al.,* 2022). The contribution of BIM to environmental protection and sustainability of projects has also become a subject of research (Heigermoser *et al.,* 2019; van Eldik *et al.,* 2020; Marzouk and Thabet, 2023). Based on the synergy of lean construction and BIM, Heigermoser *et al.* (2019) proposed a construction management tool that combines the Last Planner system with 3D visualization to achieve both productivity gains and construction waste reduction, thereby improving the efficiency and sustainability of future projects. BIM can contribute to the development of environmental impact assessments (EIA) for projects that urge project management to make more improvements in environmental protection and sustainability. Continuous BIM-based EIA allows for the systematic integration of data from multiple sources, ensuring that designers can quickly accept the results of EIA and follow up on project design improvements (van Eldik *et al.,* 2020). The above articles discussed three broad topics regarding the role of BIM in project elements and attributes, showing its impact on construction safety, quality management, and environmental protection/sustainability. Notably, the role of BIM on other project elements and attributes is also expected.

4.1.5. BIM-based collaboration and communication

Collaboration is a keyword that has received a lot of attention from academics in the field of BIM in project management. Based on semi-structured interviews, Chen *et al.* (2022) identified five types of collaborative behaviors and used a theoretical model to describe how to integrate them into BIM projects. Workload allocation is also an unavoidable issue in collaboration, and the use of workload data to enable better analysis and visualization of workload allocation patterns can help assess the impact of BIM on work allocation, allowing for improvements and further optimization of resource allocation in projects (Aibinu and Papadonikolaki, 2019). The strategic and operational decisions of collaborating organizations or institutions on a project also need to be fine-tuned as the project becomes digitized and the use of BIM increases. Research based on the boundary theory suggests that different organizations and individuals have their understanding of BIM, making communication and collaboration unsuccessful (Papadonikolaki *et al.,* 2019). However, they can be improved through structurational views such as communication, conflict management, negotiation, and teamwork (Papadonikolaki *et al.,* 2019). The above studies focused on the interaction between people, departments, institutions, and organizations in projects where BIM is used for the exchange of knowledge, information, and experience gained from the projects (Liu *et al.,* 2017; Papadonikolaki *et al.,* 2019; Chen *et al.,* 2022; Hsu *et al.*, 2023). The articles in this area of research are a good reference for collaboration and communication in practical application of BIM.

4.1.6. BIM-based information and data

Interoperability can have an impact on the interface between different processes, elements, and information in a project. The extension of the main Industry Foundation Class (IFC) standard for openBIM data exchange can be useful for BIM applications in underground construction projects such as metro stations, which contain many interdisciplinary processes, by improving the interoperability of BIM in dealing with such processes (Huang *et al.,* 2022). Furthermore, the implementation of IFC-based interoperable processes facilitates the coordination of the design and construction phases and checking of data such as models or codes, and the analysis of the construction phase by using 4D BIM (Ciribini *et al.,* 2016). As the complexity in the interoperability of information in BIM makes it more susceptible to risk-influenced uncertainty, it can also pose some contractual issues. Abd Jamil and Fathi (2020) developed a model data validation conceptual framework through semi-structured interviews with stakeholders which can help protect against data loss, corruption, or tampering of information in interoperability. The aforementioned studies demonstrated the importance of BIM-based information management and data (Ciribini *et al.,* 2016; Lu *et al.,* 2016; Abd Jamil and Fathi, 2020; Huang *et al.,* 2022; Yin *et al.,* 2023), which are of great relevance to future development of project management towards digitization and automation, and stability of information and data interaction in projects.

4.2. Research gaps of BIM in project management

This review study identified and discussed six research gaps of BIM in project management, and a summary is presented in Fig. 5.

<Please insert Figure 5 about here>

4.2.1. Integration of BIM and other digital technologies

As mentioned above, BIM is being used in project management along with many other digital technologies. As technology evolves, and innovations are invented, there are bound to be other digital technologies that could be integrated with BIM such as AR, geographic information system (GIS), virtual reality (VR), robotics, digital twin, IoTs, blockchain, etc. Among the advanced digital technologies, robotics has also attracted recent attention from researchers and practitioners. Although little research has been conducted on integrating robots and BIM in the AEC projects, Kim *et al.* (2021) have investigated the role of BIM in helping robots to carry out some indoor work on projects. The use of robots and BIM to carry out hazardous work such as working at heights, confined spaces, etc. would be very beneficial to the safety of project personnel. Future studies should be conducted on how to accelerate project schedules and improve execution accuracy. In addition, the application of BIM and wearable sensing technologies could be a potential research gap. The integration of IoT, wearable sensing technology, BIM, and GIS to monitor indoor and outdoor environments, comfort, and energy consumption data was studied by Miller *et al.* (2021), which could be useful for FM projects or energy and environmental improvements in renovation projects.

4.2.2. Future maturity of BIM applications in project management

A more mature application of BIM requires lessons learned from a wide range of projects, locations, etc. Although the barriers to BIM adoption have been addressed, previous studies have been carried out on a single type of project or geographical location, with very little research from a broader perspective. Previous studies on the use of BIM on practical projects are mostly common in specific regions or countries such as the UK, China, and Hong Kong (Georgiadou, 2019; Ding *et al.*, 2015; Chan *et al.*, 2019; Tian *et al.*, 2023). Even in African countries, where the application of BIM is still at a relatively low adoption stage, some scholars have also conducted targeted fields (Belay *et al.*, 2021). However, perhaps because BIM adoption is still relatively low in practice, and the development of BIM applications in most countries and regions has not yet reached a very mature stage. Few scholars have conducted comparative studies of BIM adoption in developed and developing countries. Nevertheless, such a comparative study would enable the identification of structure and BIM adoption in different countries (Bukhari, 2011). This can help to determine the causes of the different levels of development and inform a further spread of BIM applications in project management. Moreover, understanding the similarities and differences of BIM adoption in different countries or regions can also reveal possible directions on how BIM can be more maturely applied in different contexts.

4.2.3. Application of BIM in project components and processes

The development of project budgets and budget control is an important part of project management (Abdel-Hamid and Abdelhaleem, 2023; Zhang and Zhang, 2023). Compared to other components of projects such as simulation and FM, the role of BIM on project budgets and control has had little attention from researchers, and in particular, the aspects of BIM on the development of project budgets are even rarer. Regarding budget control, Li and Li (2020) have proposed a budget control approach using BIM for cost control of port construction projects. However, this study did not find much research input on the role of BIM in project cost and budget management, which can be considered as a research gap on BIM in project management. Perhaps a good way to explore the role of BIM in budgeting and cost control would be to combine it with simulation and decision-making. The role of BIM in budget control can be considered from various perspectives, especially as each process of a project requires cost input. It would be interesting to see how BIM could be involved and effective in the different processes of project budget control.

4.2.4. Role of BIM application in project elements and attributes

Every project is influenced by the local culture, and cultural specificity is not an unfamiliar topic in project management. The existence of cultural impact has been confirmed by a comparison of British and Arab project managers and a study of French-Dutch collaborative projects (Rees-Caldwell and Pinnington, 2013; de Bony, 2010). As part of project management, it can be assumed that culture also has an impact on BIM, but very little research has been conducted. Specifically, most articles are used to analyze the use of BIM in terms of technology, people, etc. As such, it is unknown whether different cultures in the region where the project is located hinder or benefit BIM. What impact does the cultural background of the project manager have on the use of BIM? What kind of culture is more likely to facilitate the spread of BIM in a project? If the cultural background is not conducive to the use of BIM in a project, what can be done to improve it? These research questions are yet to be explored. However, as culture and BIM are two very different concepts, conducting this research may require the collaboration of researchers with different academic backgrounds, as well as the learning of new knowledge and cumbersome communication, making it a very demanding area of research. For example, scholars from humanities, project management, and psychology disciplines can collaborate on relevant research, which may lead to the development of knowledge exchange and cooperation between different fields.

4.2.5. The impact of collaboration and communication in BIM application

Clear standards, or norms and requirements, can go a long way towards collaboration (Chen *et al.*, 2022; Hsu *et al.*, 2023). Urpelainen (2010) suggested the role of technical standards in international environmental cooperation. However, the development of clear standards for BIM can also facilitate communication and collaboration in projects and there are normative standards for the application of BIM in collaborative projects across organizations and sectors. Little existing research seems to explore the relationship between BIM and communication and collaboration in projects from this perspective, with much of the research on standards being at a technical level. For instance, a study by Lee *et al.* (2019) discussed standards for data exchange in projects. The identification of guidelines on how to communicate and manage the use of BIM in collaborative projects can lead to a more standardized and fluid process for project teams from different organizations and backgrounds. This research gap area should be conducted in future studies.

4.2.6. Stability of information and data interaction

As a concept that is not yet very far advanced, there are still some shortcomings in the application of BIM to complex projects, which have been explored by many scholars, but there are inevitably some areas for further improvement. Most of the existing research on the data aspects of BIM has focused on the transmission and exchange of data (Abd Jamil and Fathi, 2020; Huang *et al.,* 2022; Yin *et al.,* 2023). However, BIM also has the problem of large data files, which may not operate smoothly in synchronization with a large amount of information and data in the face of construction due to resource or storage limitations. At this stage, BIM requires high hardware specifications, which is not conducive to the large-scale use of BIM in projects. After all, it is not possible for all computers used in a project to have a high configuration, which would impose a significant cost burden on the companies operating the project. Further enhancement of BIM on this issue may require optimization of the packet processing capabilities of BIM itself to compress the size of the data files generated by BIM. This would facilitate the operation of BIM in a wider range of scenarios and devices, but this research gap has rarely been discussed. This type of research may need to be combined with knowledge of computer or software engineering disciplines. Collaborative research in the areas of hardware, software, and project management is likely to lead to developments in information and data interaction.

4.3. Recommendations for future research directions and contributions

There are several research directions worth recommending and studying in the future. The current review provides a summary of six suggested future research directions. A summary framework of existing research fields, research gaps, and future research directions on BIM in project management based on the qualitative discussion is shown in Fig. 6.

<Please insert Figure 6 about here>

- Integrated application of robotics and BIM.

  Exploring how to integrate robotics and BIM is like combining other digital technologies with BIM applications. Thus, how to apply robotics to make up for the shortcomings of BIM applications, or to combine their advantages to improve project management. For example, robots can help or even replace humans to carry out dangerous work at height, whilst BIM can enable robots to identify the work object more accurately, reducing errors, as well as mitigating personal safety problems that can result from working at height. Similar applications can be explored for risk identification in BIM projects and human-robot interactions.

- Comparative studies of BIM application projects in different geographical areas.

As the application of BIM varies from region to region depending on several factors, a comparative study of BIM applications in different geographical locations is more likely to enable researchers and practitioners to identify common synergies with BIM, its adaptability, and its ability to be flexibly modified to different application areas. Such differences may include climate, economy, education, and among others.

- Role of BIM in project budgets development and process control

The role of BIM in budget management and process control is recommended for further studies. For example, BIM simulations can be used to estimate the amount of consumables needed for each part of the project at the early stages of construction, thus, enhancing resources and process control. For instance, making reasonable adjustments in material resources that do not affect safety and construction can reduce the cost of the project. In addition, how to reduce waste management in projects by adopting BIM is also a potential research direction to achieve budget control.

- Cultural factors in a project and the use of BIM.

For cultural factors, it's most relevant to concentrate on the people involved in projects. Projects cannot be separated from people, nor can the application of BIM be separated from people, and people are most affected by their cultural backgrounds. Whether the cultural background of the project manager, designer, or BIM engineer has an impact on the use of BIM in a project, or their conduct and behavior on BIM application need to be explored.

- Standards for BIM application in project collaboration

The impact of standards for BIM on communication and collaboration in projects is a very novel direction. For BIM, standards are generally concerned with technical aspects as well as information storage, exchange, and security. BIM standards may not have a direct impact on communication and collaboration in a project, but the change in human behavior brought about by standardized standards can have an impact on project participants. How to guide the behavior of project participants through the development of BIM standards to further promote communication and cooperation in projects could be a crucial research direction.

- BIM for data integration and documentation

  Improving the data handling capabilities of BIM can reduce its operational equipment requirements, which may help BIM to be more widely used in projects of different sizes and budgets. Improvements in this area may involve more knowledge of computing and software engineering, and research in conjunction with academics in this area could be more efficient in arriving at methods to help improve BIM. It may also be useful to anticipate substantial changes in the use of BIM that may occur.

The findings of this study contribute to the systemic body of knowledge on BIM in project management. First, it provides a comprehensive evaluation of the influential journals, keywords, and documents analyses in this field, which could serve as a reference for other researchers interested in studying BIM applications in project management. Second, in the qualitative discussion section, the study delineates six mainstream research topics, showing the extant literature of related articles conducted on BIM in project management. Third, this study discussed the research gaps and future research directions in the domain of BIM in project management. Consequently, a new research framework was developed to assist practitioners and researchers in understanding the key areas that need to be further explored. Overall, the findings of this study provide an understanding of the state-of-the-art review and future needs of BIM in project management research, which could help researchers, policymakers, and practitioners to promote BIM and other digital innovations applications in project management.

5. Conclusions

This study aims to conduct a bibliometric and science mapping review of published articles relating to BIM in project management and to identify mainstream research topics, research gaps, and future research directions. The study found that research on BIM in project management has continued to grow from 2011 to the present and is generally on a steady increase. *Automation in Construction, Engineering, Construction and Architectural Management, Buildings, and Journal of Construction Engineering and Management* are the four journals that have contributed most to the publication of articles in this area. The most influential keywords on BIM in project management include digital twin, blockchain, barriers, virtual reality, and facilities management. The qualitative discussion delineates six mainstream research topics for BIM in project management, including (1) BIM-enabled advanced digital technologies, (2) BIM-based reinforcement and enhancement, (3) BIM and project composition, (4) BIM project elements and attributes, (5) BIM-based collaboration and communication, and (6) BIM-based information and data. Suggestions for future research directions corresponding to six research gaps were also summarized.

This review study has some limitations that need to be addressed in further studies. First, the included articles (i.e., 521 articles) analyzed in this review study were only retrieved from the Scopus database, and only articles published in Quartile 1 and 2 journals with 5 or more published articles were used. Future studies should include other databases (e.g., Web of Science, Science Direct, etc.) and articles published in other quartiles. Second, the study period was limited to articles published from 2011 to 2023 (as of 6 October 2023). Consequently, some prior existing literature samples (i.e., articles and conference papers) were missed. Future research should address this limitation by extending the studied period and including other literature samples in the domain of BIM in project management. Third, this review study didn't conduct a reliability and validity test based on the scientometric analysis. Notably, future studies should conduct the reliability and validity of the keyword co-occurrence and document analyses by providing relevant justifications from previous review studies. Despite these limitations, this study could inspire other researchers and practitioners to advance research and practice related to BIM and project management.

Data availability statement

The datasets used in this study are available from the corresponding author upon request.

Declaration of competing interest

None

References

Abd Jamil, A., and Fathi, M. (2020) Enhancing BIM-based information interoperability: dispute resolution from legal and contractual perspectives. Journal of Construction Engineering and Management, Vol. 146, No. 7, pp. 05020007. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0001868.

Abdel-Hamid, M., and Abdelhaleem, H. M. (2023) Project cost control using five dimensions building information modelling. International Journal of Construction Management, Vol. 23, No. 3, pp. 405-409. DOI: https://doi.org/10.1080/15623599.2021.1880313.

Aibinu, A., and Papadonikolaki, E. (2019) Conceptualizing and operationalizing team task interdependences: BIM implementation assessment using effort distribution analytics. Construction Management and Economics, Vol. 38, No. 5, pp. 420-446. DOI: https://doi.org/10.1080/01446193.2019.1623409.

Akram, R., Thaheem, M.J., Nasir, A.R., Ali, T.H., Khan, S. (2019) Exploring the role of building information modeling in Construction Safety through science mapping. Safety Science, Vol. 120, pp. 456–470. DOI: https://doi.org/10.1016/j.ssci.2019.07.036.

Alizadehsalehi, S., Hadavi, A., and Huang, J. (2020) From BIM to extended reality in AEC industry. Automation in Construction, Vol. 116, pp. 103254. DOI: https://doi.org/10.1016/j.autcon.2020.103254.

Alshorafa, R., and Ergen, E. (2019) Determining the level of development for BIM implementation in large-scale projects. Engineering, Construction and Architectural Management, Vol. 28, No. 1, pp. 397-423. DOI: https://doi.org/10.1108/ECAM-08-2018-0352.

Antwi-Afari, M. F., Li, H., Chan, A. H. S., Seo, J., Anwer, S., Mi, H. Y., Wu, Z., and Wong, A. Y. L. (2023) A science mapping-based review of work-related musculoskeletal disorders among construction workers. Journal of Safety Research, Vol. 85, pp. 114-128. DOI: https://doi.org/10.1016/j.jsr.2023.01.011.

Antwi-Afari, M. F., Li, H., Pärn, E. A., and Edwards, D. J. (2018) Critical success factors for implementing building information modelling (BIM): A longitudinal review. Automation in construction, Vol. 91, pp. 100-110. DOI: https://doi.org/10.1016/j.autcon.2018.03.010.

Arora, A. (2007) Dynamic project management using simulations. In: PMI® Global Congress 2007—Latin America. [online] Cancún, Mexico: Project Management Institute. Available at: <https://www.pmi.org/learning/library/dynamic-project-management-using-simulations-7328> [Accessed 4 August 2022].

Belay, S., Goedert, J., Woldesenbet, A., and Rokooei, S. (2021) Enhancing BIM implementation in the Ethiopian public construction sector: An empirical study. Cogent Engineering, Vol. 8, No. 1, pp. 1886476. DOI: https://doi.org/10.1080/23311916.2021.1886476.

Bryde, D., Broquetas, M., and Volm, J. (2013) The project benefits of building information modelling (BIM). International Journal of Project Management, Vol. 31, No. 7, pp. 971-980. DOI: https://doi.org/10.1016/j.ijproman.2012.12.001.

Bukhari, S. (2011) What is comparative study. SSRN Electronic Journal, pp. 1962328. DOI: https://doi.org/10.2139/ssrn.1962328.

Celoza, A., de Oliveira, D. P., and Leite, F. (2023) Role of BIM contract practices in stakeholder BIM implementation on AEC projects. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, Vol. 15, No. 2. DOI: https://doi.org/10.1061/JLADAH.LADR-9.

Chan, A.P.C., Ma, X., Yi, W., Zhou, X., Xiong, F. (2018) Critical Review of Studies on building information modeling (BIM) in Project Management. Frontiers of Engineering Management, Vol. 5, No. 3, pp. 394–406. DOI: https://doi.org/10.15302/j-fem-2018203.

Chan, D., Olawumi, T., and Ho, A. (2019) Critical success factors for building information modelling (BIM) implementation in Hong Kong. Engineering, Construction and Architectural Management, Vol. 26, No. 9, pp. 1838-1854. DOI: https://doi.org/10.1108/ECAM-05-2018-0204.

Chen, C. (2017) Science mapping: A systematic review of the literature. Journal of Data and

Information Science, Vol. 2, No. 2, pp. 1-40. DOI: https://doi.org/10.1515/jdis-2017-0006.

Chen, D., Zhou, J., Duan, P., and Zhang, J. (2023) Integrating knowledge management and BIM for safety risk identification of deep foundation pit construction. Engineering, Construction and Architectural Management, Vol. 30, No. 8, pp. 3242-3258. DOI: https://doi.org/10.1108/ECAM-10-2021-0934.

Chen, G., Chen, J., Tang, Y., Li, Q., and Luo, X. (2022) Identifying effective collaborative behaviors in building information modeling–enabled construction projects. Journal of Construction Engineering and Management, Vol. 148, No. 6, pp. 04022026. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0002270.

Chen, Y., Dib, H., and F. Cox, R. (2014) A measurement model of building information modelling maturity. Construction Innovation, Vol. 14, No. 2, pp. 186-209. DOI: https://doi.org/10.1108/CI-11-2012-0060.

Çıdık, M., Boyd, D., and Thurairajah, N. (2017) Ordering in disguise: digital integration in built-environment practices. Building Research & Information, Vol. 45, No. 6, pp. 665-680. DOI: https://doi.org/10.1080/09613218.2017.1309767.

Ciribini, A., Mastrolembo Ventura, S., and Paneroni, M. (2016) Implementation of an interoperable process to optimise design and construction phases of a residential building: A BIM Pilot Project. Automation in Construction, Vol. 71, pp. 62-73. DOI: https://doi.org/10.1016/j.autcon.2016.03.005.

Daniotti, B., Masera, G., Bolognesi, C., Lupica Spagnolo, S., Pavan, A., Iannaccone, G., Signorini, M., Ciuffreda, S., Mirarchi, C., Lucky, M., and Cucuzza, M. (2022) The development of a BIM-based interoperable toolkit for efficient renovation in buildings: from BIM to digital twin. Buildings, Vol. 12, No. 2, pp. 231. DOI: https://doi.org/10.3390/buildings12020231.

Dashti, M., RezaZadeh, M., Khanzadi, M., and Taghaddos, H. (2021) Integrated BIM-based simulation for automated time-space conflict management in construction projects. Automation in Construction, Vol. 132, pp. 103957. DOI: https://doi.org/10.1016/j.autcon.2021.103957.

de Bony, J. (2010) Project management and national culture: A Dutch–French case study. International Journal of Project Management, Vol. 28, No. 2, pp. 173-182. DOI: https://doi.org/10.1016/j.ijproman.2009.09.002.

de Souza, M. P., Fialho, B. C., Ferreira, R. C., Fabricio, M. M., and Codinhoto, R. (2023) Modelling and coordination of building design: an experience of BIM learning/upskilling. Architectural Engineering and Design Management, Vol. 19, No. 1, pp. 74-91. DOI: https://doi.org/10.1080/17452007.2021.1970506.

Ding, Z., Zuo, J., Wu, J., and Wang, J. (2015) Key factors for the BIM adoption by architects: a China study. Engineering, Construction and Architectural Management, Vol. 22, No. 6, pp. 732-748. DOI: https://doi.org/10.1108/ECAM-04-2015-0053.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., and McNiff, S. (2013) BIM implementation throughout the UK construction project lifecycle: An analysis. Automation in Construction, Vol. 36, pp. 145-151. DOI: https://doi.org/10.1016/j.autcon.2013.09.001.

El Ammari, K. and Hammad, A. (2019) Remote interactive collaboration in facilities management using BIM-based mixed reality. Automation in Construction, Vo. 107, pp. 102940. DOI: https://doi.org/10.1016/j.autcon.2019.102940.

Elghaish, F., Abrishami, S. and Hosseini, M. R. (2020) Integrated project delivery with blockchain: an automated financial system. Automation in Construction, Vol. 114, pp. 103182. DOI: https://doi.org/10.1016/j.autcon.2020.103182.

Faraji, A., Rashidi, M., Meydani Haji Agha, T., Rahnamayiezekavat, P., and Samali, B. (2022) Quality management framework for housing construction in a design-build project delivery system: A BIM-UAV approach. Buildings, Vol. 12, No. 5, pp. 554. DOI: https://doi.org/10.3390/buildings12050554.
Farzaneh, A., Monfet, D. and Forgues, D. (2019) Review of using building information modeling for Building Energy Modeling during the design process. Journal of Building Engineering, Vol. 23, pp. 127–135. DOI: https://doi.org/10.1016/j.jobe.2019.01.029.
Georgiadou, M. (2019) An overview of benefits and challenges of building information modelling (BIM) adoption in UK residential projects. Construction Innovation, Vol. 19, No. 3, pp. 298-320. DOI: https://doi.org/10.1108/CI-04-2017-0030.
Golparvar-Fard, M., Peña-Mora, F., and Savarese, S. (2011) Integrated sequential as-built and as-planned representation with D 4 AR tools in support of decision-making tasks in the AEC/FM industry. Journal of Construction Engineering and Management, Vol. 137, No. 12, pp. 1099-1116. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000371.
He, Q., Wang, G., Luo, L., Shi, Q., Xie, J., Meng, X. (2017) Mapping the managerial areas of building information modeling (BIM) using scientometric analysis. International Journal of Project Management, Vol. 35, No. 4, pp. 670–685. DOI: https://doi.org/10.1016/j.ijproman.2016.08.001.
Heigermoser, D., García de Soto, B., Abbott, E., and Chua, D. (2019) BIM-based last planner system tool for improving construction project management. Automation in Construction, Vol. 104, pp. 246-254. DOI: https://doi.org/10.1016/j.autcon.2019.03.019.
Hsu, C. L., Wang, J. T., and Hou, H. Y. (2023) A blockchain-based parametric model library for knowledge sharing in building information modeling collaboration. Journal of Construction Engineering and Management, Vol. 149, No. 11, pp. 04023107. DOI: https://doi.org/10.1061/JCEMD4.COENG-130.
Huang, M., Zhu, H., Ninić, J., and Zhang, Q. (2022) Multi-LOD BIM for underground metro station: Interoperability and design-to-design enhancement. Tunnelling and Underground Space Technology, Vol. 119, pp. 104232. DOI: https://doi.org/10.1016/j.tust.2021.104232.
Hyarat, E., Hyarat, T., and Al Kuisi, M. (2022) Barriers to the implementation of building information modeling among Jordanian AEC companies. Buildings, Vol. 12, No. 2, pp. 150. DOI: https://doi.org/10.3390/buildings12020150.
Ivson, P., Moreira, A., Queiroz, F., Santos, W., Celes, W. (2020) A systematic review of visualization in building information modeling. IEEE Transactions on Visualization and Computer Graphics, Vol. 26, No. 10, pp. 3109–3127. DOI: https://doi.org/10.1109/tvcg.2019.2907583.
Jang, S., and Lee, G. (2018) Process, productivity, and economic analyses of BIM–based multi-trade prefabrication—A case study. Automation in Construction, Vol. 89, pp. 86-98. DOI: https://doi.org/10.1016/j.autcon.2017.12.035.
Jaradat, S., Whyte, J., and Luck, R. (2013) Professionalism in digitally mediated project work. Building Research and Information, Vol. 41, No. 1, pp. 51-59. DOI: https://doi.org/10.1080/09613218.2013.743398.
Jin, R., Zou, P., Piroozfar, P., Wood, H., Yang, Y., Yan, L., and Han, Y. (2019) A science mapping approach based review of construction safety research. Safety Science, Vol. 113, pp. 285-297. DOI: https://doi.org/10.1016/j.ssci.2018.12.006.
Kamel, E., and Memari, A. (2019) Review of BIM's application in energy simulation: Tools, issues, and solutions. Automation in Construction, Vol. 97, pp. 164-180. DOI: https://doi.org/

10.1016/j.autcon.2018.11.008.
Kim, S., Peavy, M., Huang, P., and Kim, K. (2021) Development of BIM-integrated construction robot task planning and simulation system. Automation in Construction, Vol. 127, pp. 103720. DOI: https://doi.org/10.1016/j.autcon.2021.103720.
Kim, T., Yoon, Y., Lee, B., Ham, N., and Kim, J. J. (2022) Cost–benefit analysis of scan-vs-BIM-based quality management. Buildings, Vol. 12, No. 12, pp. 2052. DOI: https://doi.org/10.3390/buildings12122052.
Koo, H., and O'Connor, J. (2022) A strategy for building design quality improvement through BIM capability analysis. Journal of Construction Engineering and Management, Vol. 148, No. 8, pp. 04022066. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0002318.
Lee, Y., Solihin, W., and Eastman, C. (2019) The mechanism and challenges of validating a building information model regarding data exchange standards. Automation in Construction, Vol. 100, pp. 118-128. DOI: https://doi.org/10.1016/j.autcon.2018.12.025.
Li, C., Xue, F., Li, X., Hong, J., and Shen, G. (2018) An internet of things-enabled BIM platform for on-site assembly services in prefabricated construction. Automation in Construction, Vol. 89, pp. 146-161. DOI: https://doi.org/10.1016/j.autcon.2018.01.001.
Li, L., Qu, T., Liu, Y., Zhong, R. Y., Xu, G., Sun, H., Gao, Y., Lei, B., Mao, C., Pan, Y., Wang, F., and Ma, C. (2020) Sustainability assessment of intelligent manufacturing supported by digital twin. IEEE Access, Vol. 8, pp. 174988-175008. DOI: https://doi.org/10.1109/ACCESS.2020.3026541.
Li, X., Lu, W., Xue, F., Wu, L., Zhao, R., Lou, J., and Xu, J. (2022) Blockchain-enabled IoT-BIM platform for supply chain management in modular construction. Journal of Construction Engineering and Management, Vol. 148, No. 2, pp. 04021195. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0002229.
Li, X., Wu, P., Shen, G.Q., Wang, X., Teng, Y. (2017) Mapping the knowledge domains of building information modeling (BIM): A Bibliometric approach. Automation in Construction, Vol. 84, pp. 195–206. DOI: https://doi.org/10.1016/j.autcon.2017.09.011.
Li, Y., and Li, Q. (2020) The application of BIM technology in budget control of port construction cost. Journal of Coastal Research, Vol. 103, No. sp1, pp. 644. DOI: https://doi.org/10.2112/SI103-131.1.
Lin, Y. C., Hsu, Y. T., and Hu, H. T. (2022) BIM model management for BIM-based facility management in buildings. Advances in Civil Engineering, Vol. 2022, pp. 1-13. DOI: https://doi.org/10.1155/2022/1901201.
Liu, H., Zhang, R., Zhang, H., Jiang, H., Ju, Q., Fu, H. (2022) Identification and analysis of key barriers of BIM application for small- and medium-sized fire protection enterprises. Journal of Environmental and Public Health, Vol. 2022, pp. 1–19. DOI: https://doi.org/10.1155/2022/9240224.
Liu, Y., van Nederveen, S., and Hertogh, M. (2017) Understanding effects of BIM on collaborative design and construction: An empirical study in China. International Journal of Project Management, Vol. 35, No. 4, pp. 686-698. DOI: https://doi.org/10.1016/j.ijproman.2016.06.007.
Love, P. E., Matthews, J., Simpson, I., Hill, A., and Olatunji, O. A. (2014) A benefits realization management building information modeling framework for asset owners. Automation in construction, Vol. 37, pp. 1-10. DOI: https://doi.org/10.1016/j.autcon.2013.09.007.
Lu, Q., Won, J. and Cheng, J.C.P. (2016) A financial decision making framework for construction projects based on 5D building information modeling (BIM). International Journal of

Project Management, Vol. 34, No. 1, pp. 3–21. DOI: https://doi.org/10.1016/j.ijproman.2015.09.004.

Lu, Y., Wu, Z., Chang, R., Li, Y. (2017) Building Information Modeling (BIM) for Green Buildings: A Critical Review and future directions. Automation in Construction, Vol. 83, pp. 134–148. DOI: https://doi.org/10.1016/j.autcon.2017.08.024.

Ma, X., Chan, A., Li, Y., Zhang, B., and Xiong, F. (2020) Critical strategies for enhancing BIM implementation in AEC projects: perspectives from Chinese practitioners. Journal of Construction Engineering and Management, Vol. 146, No. 2, pp. 05019019. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0001748.

Malhotra, A., Shamovich, M., Frisch, J., and van Treeck, C. (2022) Urban energy simulations using open CityGML models: A comparative analysis. Energy and Buildings, Vol. 255, pp. 111658. DOI: https://doi.org/10.1016/j.enbuild.2021.111658.

Martínez-Aires, M.D., López-Alonso, M. and Martínez-Rojas, M. (2018) Building Information Modeling and Safety Management: A systematic review. Safety Science, Vol. 101, pp. 11–18. DOI: https://doi.org/10.1016/j.ssci.2017.08.015.

Marzouk, M., and Thabet, R. (2023) A BIM-based tool for assessing sustainability in buildings using the green pyramid rating system. Buildings, Vol. 13, No. 5, pp. 1274. DOI: https://doi.org/10.3390/buildings13051274.

Matarneh, S.T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., Matarneh, R. (2019) Building information modeling for Facilities Management: A literature review and future research directions. Journal of Building Engineering, Vol. 24, pp. 100755. DOI: https://doi.org/10.1016/j.jobe.2019.100755.

Maude, F. (2011) Government Construction Strategy. London: The Minister for the Cabinet Office, pp. 13-14.

May, K., KC, C., Ochoa, J., Gu, N., Walsh, J., Smith, R., and Thomas, B. (2022) The identification, development, and evaluation of BIM-ARDM: A BIM-Based AR defect management system for construction inspections. Buildings, Vol. 12, No. 2, pp. 140. DOI: https://doi.org/10.3390/buildings12020140.

McGraw Hill Construction (2012) The business value of BIM in North America - multi year trend analysis and user ratings. Smart Market Report, pp. 1-72. Available at: <https://images.autodesk.com/adsk/files/mhc_business_value_of_bim_in_north_america_2007-2012_smr.pdf> [Accessed 28 March 2022].

Miller, C., Abdelrahman, M., Chong, A., Biljecki, F., Quintana, M., Frei, M., Chew, M., and Wong, D. (2021) The internet-of-buildings (IoB) — digital twin convergence of wearable and IoT data with GIS/BIM. Journal of Physics: Conference Series, Vol. 2042, No. 1, pp. 012041. DOI: https://doi.org/10.1088/1742-6596/2042/1/012041.

Mongeon, P., and Paul-Hus, A. (2015) The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics, Vol. 106, No. 1, pp. 213-228. DOI: https://doi.org/10.1007/s11192-015-1765-5.

Moshtaghian, F., and Noorzai, E. (2023) Integration of risk management within the building information modeling (BIM) framework. Engineering, Construction and Architectural Management, Vol. 30, No. 5, pp. 1951-1977. DOI: https://doi.org/10.1108/ECAM-04-2021-0327.

Nagy, J., Oláh, J., Erdei, E., Máté, D., and Popp, J. (2018) The role and impact of Industry 4.0 and the internet of things on the business strategy of the value chain—the case of Hungary. Sustainability, Vol. 10, No. 10, pp. 3491. DOI:

https://doi.org/10.3390/su10103491.
Olanrewaju, O., Kineber, A., Chileshe, N., and Edwards, D. (2022) Modelling the relationship between building information modelling (BIM) implementation barriers, usage and awareness on building project lifecycle. Building and Environment, Vol. 207, pp. 108556. DOI: https://doi.org/10.1016/j.buildenv.2021.108556.
Oraee, M., Hosseini, M., Papadonikolaki, E., Palliyaguru, R., and Arashpour, M. (2017) Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. International Journal of Project Management, Vol. 35, No. 7, pp. 1288-1301. DOI: https://doi.org/10.1016/j.ijproman.2017.07.001.
Pan, Y., and Zhang, L. (2021) A BIM-data mining integrated digital twin framework for advanced project management. Automation in Construction, Vol. 124, pp. 103564. DOI: https://doi.org/10.1016/j.autcon.2021.103564.
Panya, D. S., Kim, T., and Choo, S. (2023). An interactive design change methodology using a BIM-based virtual reality and augmented reality. Journal of Building Engineering, Vol. 68, pp. 106030. DOI: https://doi.org/10.1016/j.jobe.2023.106030.
Papadonikolaki, E., van Oel, C., and Kagioglou, M. (2019) Organising and managing boundaries: a structurational view of collaboration with building information modelling (BIM). International Journal of Project Management, Vol. 37, No. 3, pp. 378-394. DOI: https://doi.org/10.1016/j.ijproman.2019.01.010.
Park, C. S., Lee, D. Y., Kwon, O. S., and Wang, X. (2013) A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. Automation in construction, Vol. 33, pp. 61-71. DOI: https://doi.org/10.1016/j.autcon.2012.09.010.
Perianes-Rodriguez, A., Waltman, L., and van Eck, N. (2016) Constructing bibliometric networks: A comparison between full and fractional counting. Journal of Informetrics, Vol. 10, No. 4, pp. 1178-1195. DOI: https://doi.org/10.1016/j.joi.2016.10.006.
Pishdad-Bozorgi, P., Gao, X., Eastman, C., and Self, A. (2018) Planning and developing facility management-enabled building information model (FM-enabled BIM). Automation in Construction, Vol. 87, pp. 22-38. DOI: https://doi.org/10.1016/j.autcon.2017.12.004.
Potrč Obrecht, T., Röck, M., Hoxha, E., and Passer, A. (2020). BIM and LCA integration: A systematic literature review. Sustainability, Vol. 12, No. 14, pp. 5534. DOI: https://doi.org/10.3390/su12145534.
Pour Rahimian, F., Seyedzadeh, S., Oliver, S., Rodriguez, S., and Dawood, N. (2020) On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning. Automation in Construction, Vol. 110, pp. 103012. DOI: https://doi.org/10.1016/j.autcon.2019.103012.
Ramos-Rodríguez, A.-R., Ruíz-Navarro, J. (2004) Changes in the intellectual structure of strategic management research: a bibliometric study of the Strategic Management Journal, 1980-2000. Strategic Management Journal, Vol. 25, pp. 981e1004. DOI: https://doi.org/10.1002/smj.397.
Rees-Caldwell, K., and Pinnington, A. (2013) National culture differences in project management: Comparing British and Arab project managers' perceptions of different planning areas. International Journal of Project Management, Vol. 31, No. 2, pp. 212-227. DOI: https://doi.org/10.1016/j.ijproman.2012.04.003.
Ren, G., Li, H., Liu, S., Goonetillake, J., Khudhair, A., and Arthur, S. (2021) Aligning BIM and ontology for information retrieve and reasoning in value for money

assessment. Automation in Construction, Vol. 124, pp. 103565. DOI: https://doi.org/10.1016/j.autcon.2021.103565.

Saka, A. B., and Chan, D.W.M. (2019) A scientometric review and metasynthesis of building information modelling (BIM) research in Africa. Buildings, Vol. 9, No. 4, pp. 85. DOI: https://doi.org/10.3390/buildings9040085.

Sanhudo, L., Poças Martins, J., Ramos, N., Almeida, R., Rocha, A., Pinto, D., Barreira, E. and Simões, M. (2020) BIM framework for the specification of information requirements in energy-related projects. Engineering, Construction and Architectural Management, Vol. 28, No. 10, pp. 3123-3143. DOI: https://doi.org/10.1108/ECAM-07-2020-0488.

Sanhudo, L., Ramos, N.M.M., Martins, J.P., Almeida, R.M.S.F., Barreira, E., Simões, M.L., Cardoso, V. (2018) Building information modeling for Energy Retrofitting – A Review. Renewable and Sustainable Energy Reviews, Vol. 89, pp. 249–260. DOI: https://doi.org/10.1016/j.rser.2018.03.064.

Santos, R., Costa, A.A., Silvestre J.D., Pyl, L. (2019) Informetric analysis and review of literature on the role of BIM in sustainable construction. Automation in Construction, Vol. 103, pp. 221–234. DOI: https://doi.org/10.1016/j.autcon.2019.02.022.

Sezer, A., and Bröchner, J. (2019) Site managers' ICT tools for monitoring resources in refurbishment. Engineering, Construction and Architectural Management, Vol. 27, No. 1, pp. 109-127. DOI: https://doi.org/10.1108/ECAM-02-2018-0074.

Shi, J., and Antwi-Afari, M. F. (2023) Organizational leadership and employee well-being in the construction industry: a bibliometric and scientometric review. Journal of Engineering, Design and Technology, Vol. ahead-of-print No. ahead-of-print. DOI: https://doi.org/10.1108/JEDT-05-2023-0174.

Small, H. (1999). Visualizing science by citation mapping. Journal of the American Society for Information Science, Vol. 50, No. 9, pp. 799-813. DOI: https://doi.org/10.1002/(SICI)1097-4571(1999)50:9<799: AID-ASI9>3.0.CO;2-G.

Su, H., and Lee, P. (2010) Mapping knowledge structure by keyword co-occurrence: a first look at journal papers in Technology Foresight. Scientometrics, Vol. 85, No. 1, pp. 65-79. DOI: https://doi.org/10.1007/s11192-010-0259-8.

Sun, W., Antwi-Afari, M. F., Mehmood, I., Anwer, S., and Umer, W. (2023) Critical success factors for implementing blockchain technology in construction. Automation in Construction, Vol. 156, pp. 105135. DOI: https://doi.org/10.1016/j.autcon.2023.105135.

Tak, A., Taghaddos, H., Mousaei, A., Bolourani, A., and Hermann, U. (2021) BIM-based 4D mobile crane simulation and onsite operation management. Automation in Construction, Vol. 128, pp. 103766. DOI: https://doi.org/10.1016/j.autcon.2021.103766.

Tang, Y., Xia, N., Lu, Y., Varga, L., Li, Q., Chen, G., and Luo, J. (2021) BIM-based safety design for emergency evacuation of metro stations. Automation in Construction, Vol. 123, pp. 103511. DOI: https://doi.org/10.1016/j.autcon.2020.103511.

Tao, X., Wong, P. K. Y., Xu, Y., Liu, Y., Gong, X., Zheng, C., Das, M., and Cheng, J. C. (2023) Smart contract swarm and multi-branch structure for secure and efficient BIM versioning in blockchain-aided common data environment. Computers in Industry, Vol. 149, pp. 103922. DOI: https://doi.org/10.1016/j.compind.2023.103922.

Tian, L., Wright, A., Painter, B., and Pazhoohesh, M. (2023) Factors influencing BIM use in green building construction project management in the UK and China. Building Research & Information, Vol. 51, No. 7, pp. 1-18. DOI: https://doi.org/10.1080/09613218.2023.2213356.

Urpelainen, J. (2010) Enforcing international environmental cooperation: Technological standards can help. The Review of International Organizations, Vol. 5, No. 4, pp. 475-496. DOI: https://doi.org/10.1007/s11558-010-9086-1.

van Eck, N., and Waltman, L. (2009) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, Vol. 84, No. 2, pp. 523-538. DOI: https://doi.org/10.1007/s11192-009-0146-3.

van Eldik, M., Vahdatikhaki, F., dos Santos, J., Visser, M., and Doree, A. (2020) BIM-based environmental impact assessment for infrastructure design projects. Automation in Construction, Vol. 120, pp. 103379. DOI: https://doi.org/10.1016/j.autcon.2020.103379.

Wijekoon, C., Manewa, A., and Ross, A. (2018) Enhancing the value of facilities information management (FIM) through BIM integration. Engineering, Construction and Architectural Management, Vol. 27, No. 4, pp. 809-824. DOI: https://doi.org/10.1108/ECAM-02-2016-0041.

Wing, C. K. (1997) The ranking of construction management journals. Construction Management and Economics, Vol. 15, No. 4, pp. 387–398. DOI: https://doi.org/10.1080/014461997372953.

Wong, J. K. W., and Zhou, J. (2015) Enhancing environmental sustainability over building life cycles through green BIM: A review. Automation in construction, Vol. 57, pp. 156-165. DOI: https://doi.org/10.1016/j.autcon.2015.06.003.

Wu, Z., Deng, K., Chen, C., Li, H., Antwi-Afari, M. F., and Wang, Y. (2022) Status quo and future trends of BIM-based coordination research: a critical review. Journal of Civil Engineering and Management, Vol. 28, No. 6, pp. 469-484. DOI: https://doi.org/10.3846/jcem.2022.16928.

Yin, M., Tang, L., Webster, C., Xu, S., Li, X., and Ying, H. (2023) An ontology-aided, natural language-based approach for multi-constraint BIM model querying. Journal of Building Engineering, Vol. 76, pp. 107066. DOI: https://doi.org/10.1016/j.jobe.2023.107066.

Zhang, H. M., Chong, H.-Y., Zeng, Y., and Zhang, W. (2023) The effective mediating role of stakeholder management in the relationship between BIM implementation and project performance. Engineering, Construction and Architectural Management, Vol. 30, No. 6, pp. 2503-2522. DOI: https://doi.org/10.1108/ECAM-04-2020-0225.

Zhang, J., and El-Gohary, N. M. (2017) Integrating semantic NLP and logic reasoning into a unified system for fully-automated code checking. Automation in construction, Vol. 73, pp. 45-57. DOI: https://doi.org/10.1016/j.autcon.2016.08.027.

Zhang, S., Boukamp, F., and Teizer, J. (2015b) Ontology-based semantic modeling of construction safety knowledge: Towards automated safety planning for job hazard analysis (JHA). Automation in Construction, Vol. 52, pp. 29-41. DOI: https://doi.org/10.1016/j.autcon.2015.02.005.

Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C. M., and Teizer, J. (2015) BIM-based fall hazard identification and prevention in construction safety planning. Safety Science, Vol. 72, pp. 31–45. DOI: https://doi.org/10.1016/j.ssci.2014.08.001.

Zhang, S., Teizer, J., Lee, J., Eastman, C. and Venugopal, M. (2013) Building information modeling (BIM) and safety: automatic safety checking of construction models and schedules. Automation in Construction, Vol. 29, pp. 183-195. DOI: https://doi.org/10.1016/j.autcon.2012.05.006.

Zhang, X., and Zhang, X. (2023) An automated project carbon planning, monitoring and forecasting system integrating building information model and earned value method. Journal of Cleaner Production, Vol. 397, pp. 136526. DOI:

https://doi.org/10.1016/j.jclepro.2023.136526.

Zheng, X., Le, Y., Chan, A.P.C., Hu, Y., Li, Y. (2016) Review of the application of social network analysis (SNA) in construction project management research. International Journal of Project Management, Vol. 34, pp. 1214e1225. DOI: https://doi.org/10.1016/j.ijproman.2016.06.005.

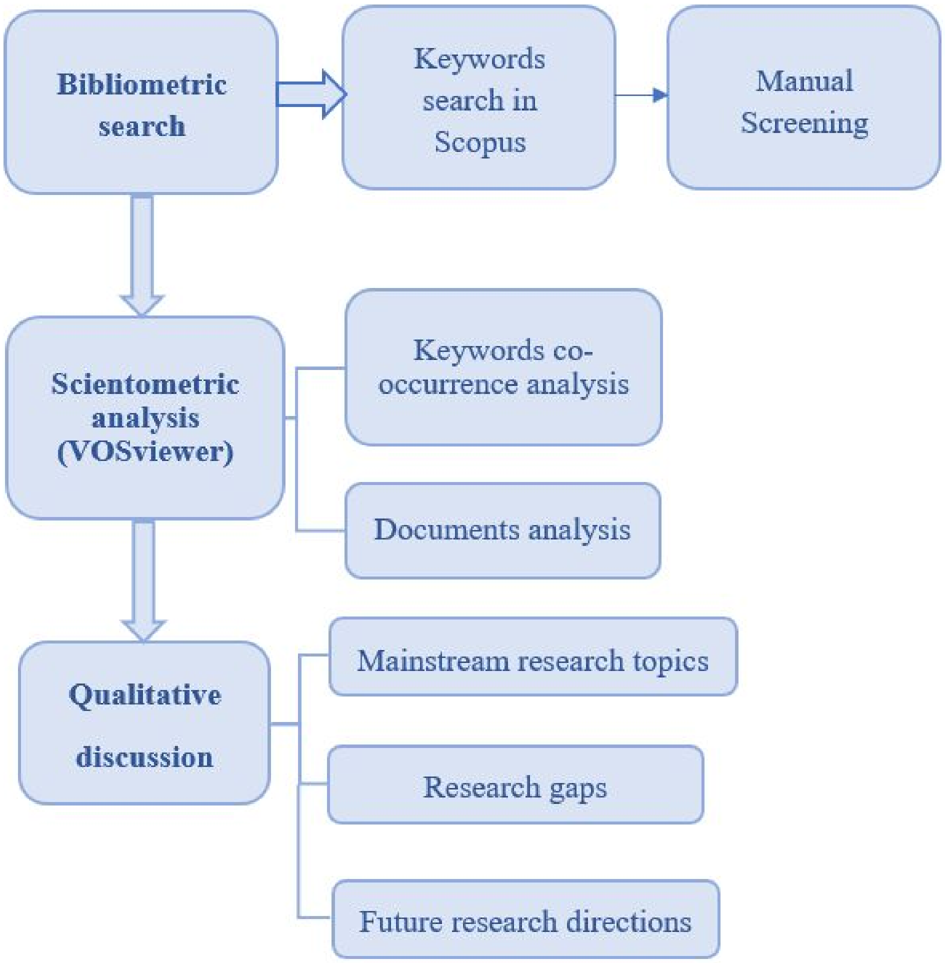

Fig 1. Overview of research methodology

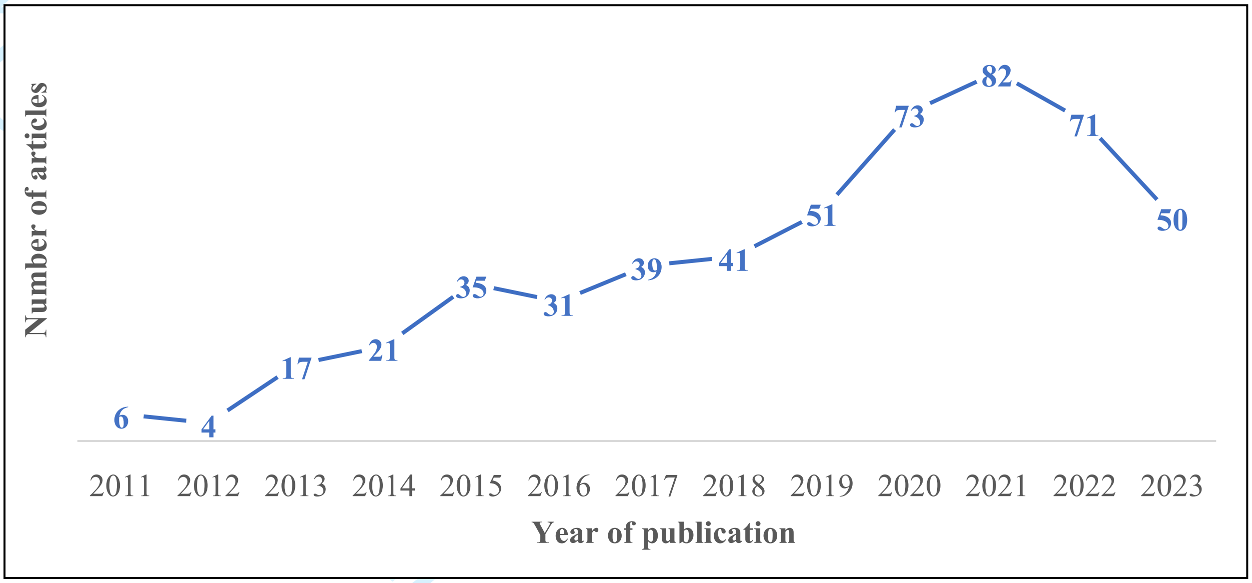

Fig 2. Annual publication trend of the selected articles retrieved from the Scopus database. Note: The search was conducted on 6 October 2023

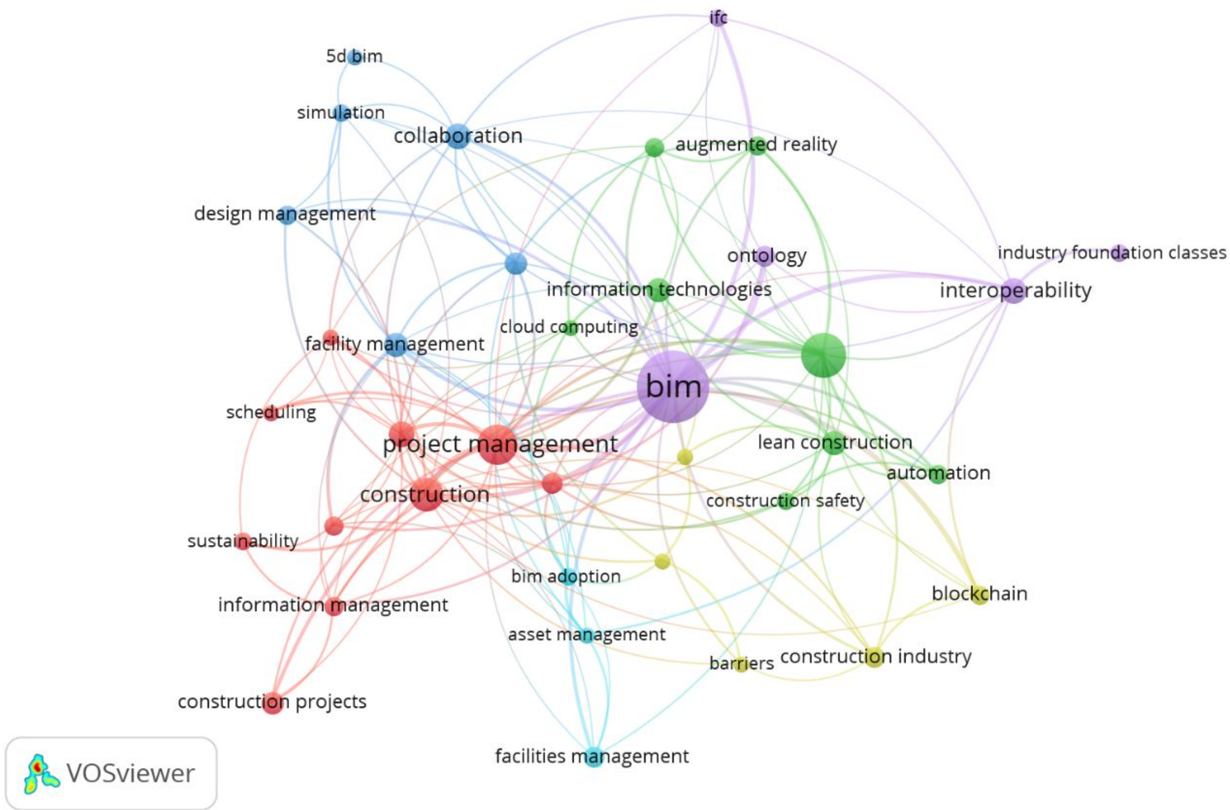

Fig 3. Network visualization of keyword co-occurrence analysis

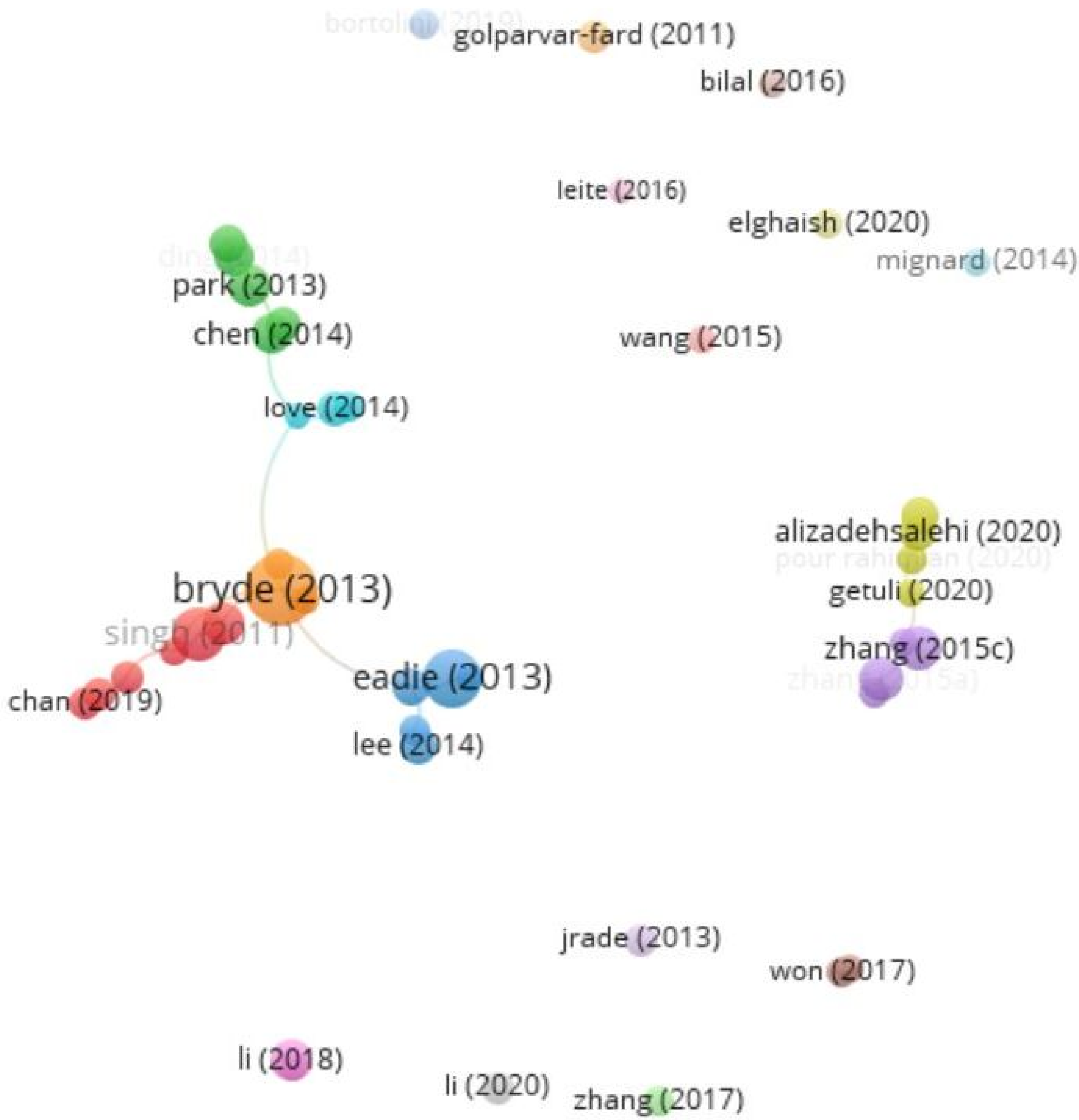

Fig 4. Network visualization of document analysis

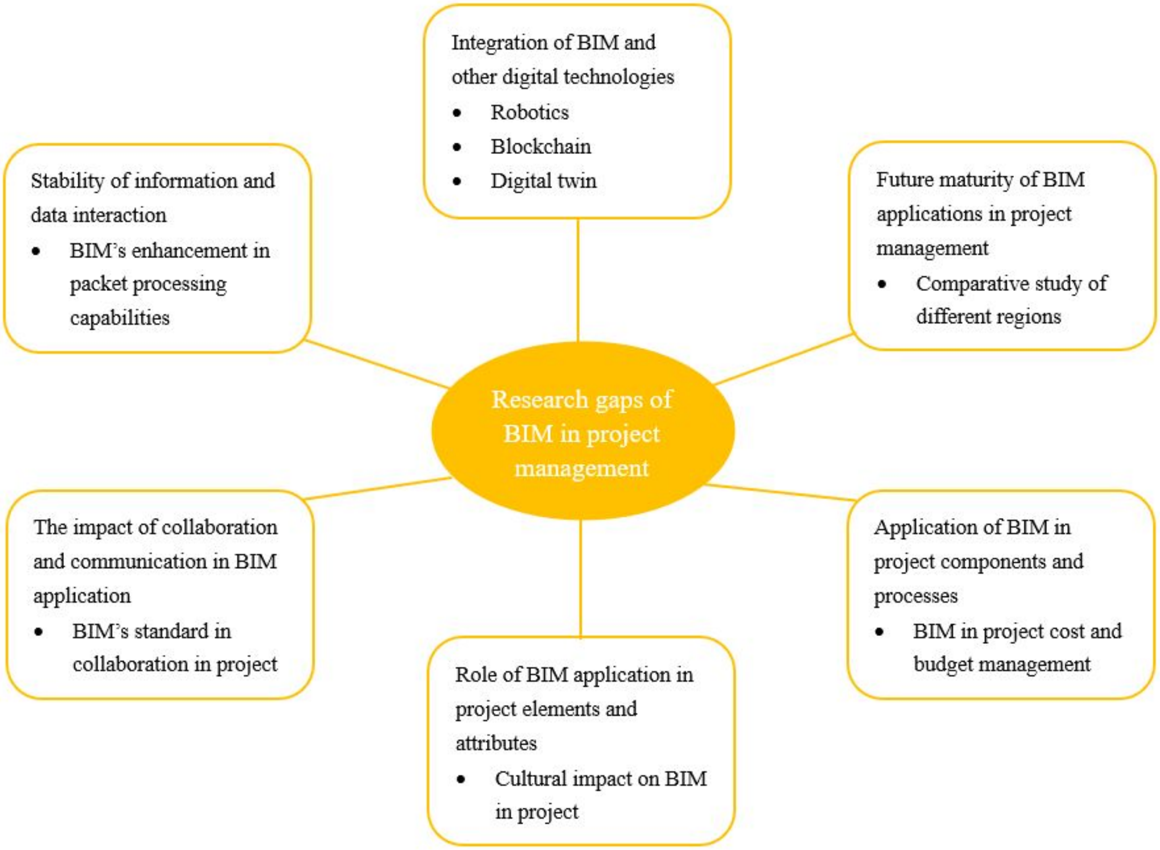

Fig. 5. Research gaps of BIM in project management

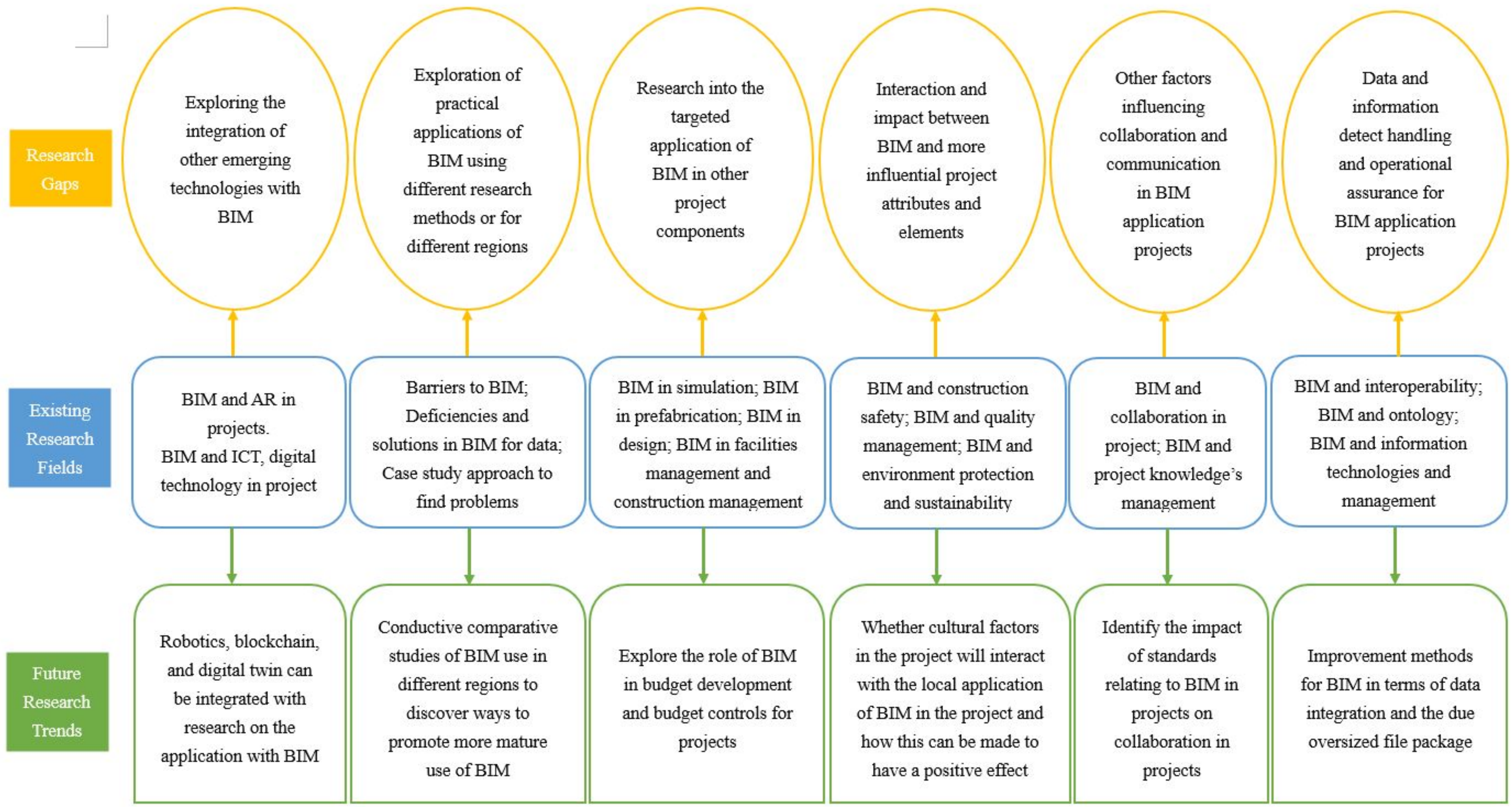

Fig. 6. Proposed framework showing the interconnections among existing research fields, research gaps and future research directions

Table 1. Keywords and literature search results in the Scopus database

Search string	**Results**
(TITLE-ABS-KEY (building information modelling) AND TITLE-ABS-KEY (project management))	4,215
AND PUBYEAR > 2010 to PUBYEAR < 2023	3,713
AND (LIMIT-TO (PUBSTAGE, “final”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SUBJAREA, “ENGI”) OR LIMIT-TO (SUBJAREA, “BUSI”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SRCTYPE, “j”))	1,205
Excluding journals except quartiles 1 and 2 (according to journal citation report in Web of Science) with 5 or more published articles	638
Included articles after manual screening (i.e., reading abstracts and full texts)	521
Note: The Scopus search was conducted in October 2023	

Table 2. Summary of selected peer-reviewed journals

Journals	Number of relevant articles	% of total publications
Automation in Construction	98	18.81%
Engineering, Construction and Architectural Management	51	9.79%
Buildings	45	8.64%
Journal of Construction Engineering and Management	42	8.06%
Journal of Information Technology in Construction	40	7.68%
Construction Management and Economics	39	7.49%
Applied Sciences (Switzerland)	34	6.53%
Journal of Management in Engineering	30	5.76%
International Journal of Project Management	22	4.22%
Journal of Civil Engineering and Management	20	3.84%
Journal of Computing in Civil Engineering	18	3.45%
Journal of Building Engineering	17	3.26%
Architectural Engineering and Design Management	12	2.30%
Journal of Engineering, Design and Technology	10	1.92%
Computers in Industry	7	1.34%
IEEE Access	7	1.34%
Building Research and Information	5	0.96%
Sustainable Cities and Society	5	0.96%
Tunnelling and Underground Space Technology	5	0.96%
Building and Environment	4	0.77%
Journal of Cleaner Production	4	0.77%
Journal of Legal Affairs and Dispute Resolution in Engineering and Construction	4	0.77%
Safety Science	2	0.38%
Total	**521**	**100.00%**

Table 3. Quantitative summary of the influence of keywords on BIM in project management

Keywords	Occurrences	Average publication year	Average citations	Average normalized citations
Digital twin	9	2021	64	2.92
Blockchain	9	2022	30.22	2.83
Barriers	6	2021	51.17	2.33
Virtual reality	8	2019	63.38	1.76
Facilities management	10	2018	97.8	1.57
Construction safety	7	2018	69.29	1.55
Cloud computing	6	2016	89.33	1.54
Ontology	10	2017	106.8	1.43
Sustainability	7	2018	71.86	1.39
BIM adoption	7	2018	115.57	1.39
BIM implementation	6	2020	60.83	1.37
Automation	9	2021	18.67	1.26
Integrated project delivery	6	2020	54	1.26
Collaboration	16	2019	61.88	1.25
Augmented reality	9	2020	54.11	1.21
Design	6	2017	88.5	1.21
5D BIM	6	2020	46.5	1.2
Construction projects	12	2021	23.83	1.19
Construction industry	10	2020	25.7	1.15
Lean construction	13	2019	45.77	1.09
Knowledge management	10	2018	51.1	1.09
Interoperability	16	2020	33.62	1.08
Information technologies	14	2016	69	1.04
Simulation	7	2017	59.29	1.04
Case study	16	2019	30.56	1.03
Design management	8	2019	23.5	1.02
BIM	116	2019	37.62	1
Industry foundation classes (IFC)	7	2019	32	0.97
Construction management	45	2018	37.11	0.96
Construction	25	2019	56.64	0.91
Information management	9	2017	45.89	0.89
Asset management	6	2020	30	0.89
Integration	12	2019	32.75	0.76
Project management	35	2018	39.86	0.65
Scheduling	6	2020	16	0.47

Table 4. Summary of the top 10 selected highly cited articles on BIM in project management

Articles	**Titles**	**Total citations**	**Normalized citations**
Pan and Zhang (2021)	A BIM-data mining integrated digital twin framework for advanced project management	179	10.24
Alizadehsalehi et al. (2020)	From BIM to extended reality in AEC industry	176	5.27
Li et al. (2018)	An Internet of Things-enabled BIM platform for on-site assembly services in prefabricated construction	241	5.21
Bryde et al. (2013)	The project benefits of building information modelling (BIM)	677	4.99
Li et al. (2020)	Sustainability assessment of intelligent manufacturing supported by digital twin	151	4.52
Zhang et al. (2015)	BIM-based fall hazard identification and prevention in construction safety planning	263	4.47
Liu et al. (2017)	Understanding effects of BIM on collaborative design and construction: An empirical study in China	227	4.39
Zhang et al. (2015b)	Ontology-based semantic modeling of construction safety knowledge: Towards automated safety planning for job hazard analysis (JHA)	244	4.15
Pour Rahimian et al. (2020)	On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning	129	3.86
Pishdad-bozorgi et al. (2018)	Planning and developing facility management-enabled building information model (FM-enabled BIM)	175	3.78