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REVIEW PAPER

A review of construction management challenges and BIM-based solutions: perspectives from the schedule, cost, quality, and safety management

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Abstract

Efficient project delivery in the context of contemporary construction management is dependent on large volumes of data. However, due to pertinent challenges underlying implementation, easy access to key construction management data remains a significant hurdle. Management is quickly transforming to facilitate the employment of predictive decision-making methods, wherein the digitalization of construction data functions as a crucial component. The Architectural, Engineering, and Construction (AEC) industry has been trailing behind in the implementation of modern management concepts as well as novel technologies. However, it is vital to re-engineer construction management to be on par with other related industries, such as manufacturing, oil, and gas. The advent of Building Information Modeling (BIM) has been attributed to the paradigm shift that construction management is currently undergoing. BIM is a platform equipped with unique and effective tools to support the implementation of management techniques. This research critically reviews challenges plaguing conventional construction management and decision-making solutions for construction management as devised by BIM. This review focuses on construction management's four key bottom lines (i.e., schedule, cost, quality, and safety management) and how a BIM-based construction management platform helps monitor these aspects. This review revealed that the primary focus of the researchers was to develop BIM-based automated prediction models and enhance communication and collaboration among project participants. Based on the findings of this research, a BIM-based construction decision-making framework was proposed. This roadmap provides construction organizations with the information required to implement a BIM-based decision support system for project management. Finally, the research identified several knowledge gaps and the potential for future research.

Keywords Construction management · Building information modeling · Predictive decision-making · BIM

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Introduction

The Architectural, Engineering, and Construction (AEC) industry plays a crucial role in the socio-economic development of a country (Oladinrin et al., 2012), (Wells, 1985). In fact, the construction sector accounts for 6.7% and 7% of the Gross Domestic Product (GDP) of the United Kingdom and Canada, respectively (DBIS, 2013). Typically, this industry employs a significant portion of a nation's workforce, and thus, efficient management of the AEC industry has direct implications for the national economy. However, the AEC industry has been slow at studying and employing modern management tools, techniques, and practices and is criticized for not directing optimal efforts toward leveraging the collaborative work nature (Ahuja et al., 2010; Lam et al., 2010; Martínez-rojas et al., 2016; Sardroud, 2015).

The key bottom lines of the AEC industry are schedule, cost, quality, and safety considerations, which is a particularly accurate assumption in the context of construction project management (Doloi, 2013; Khademi, 2014; Memon et al., 2011). To efficiently resolve construction management challenges by executive relevant solutions, the AEC industry must explore and analyze innovative management solutions being successfully applied by other industries (e.g., manufacturing, oil, and gas). Other related industries, such as manufacturing, oil, and gas, have been successful at optimizing the efficiency of their processes by leveraging innovative decision support methods integrated with Enterprise Resource Planning (ERP) systems (Raicu et al., 2017).

In the recent past, modern technologies, such as Geographic Information Systems (GIS), Artificial Intelligence (AI), smart structural monitoring and sensing technologies, augmented reality, and virtual prototyping, have been quickly making their mark in the construction sector (Faghihi et al., 2015; Martinez-Rojas et al., 2018; Martínez-rojas et al., 2016). Modern innovations, such as digital twinning, 3D virtual reality systems, cloud solutions, mobile apps, and AI, among others, can potentially transform the future of the AEC industry (Blazquez, 2014; Demirkan, 2015; Pantano et al., 2017; Papagiannidis et al., 2013). However, the dynamic nature and the complexities surrounding the AEC industry, such as frequent changes in regulations (e.g., safety and sustainability), fluctuating workload, multiple role demands, conflicts, stressful workforce, inflation, learning curves, climate change, weather impacts, lack of workmanship, poor quality materials, and numerous change requests continue to pose challenges to the construction managers (Awwad et al., 2016; Dodanwala & Santoso, 2022; Dodanwala & Shrestha, 2021; Dodanwala et al., 2021, 2022a, b; Turner et al., 2008). Consequently, it is imperative to take into account an array of variables during the decision-making process within the construction environment, making it an arduous task.

Since construction projects involve multiple stakeholders, there is a constant exchange of a large amount of data within short periods of time (Crotty, 2012; Latiffi et al., 2014). In the face of reliable, accurate, and readily available data, the construction sector can transform into a "smarter industry," expanding its data storage, monitoring techniques, and decision-making capacities. The lack of project data coordination (Chassiakos & Sakellaropoulos, 2008; Forcada et al., 2007), technological awareness, and state-of-the-art techniques in the construction industry (Adriaanse et al., 2010; Y. Lu et al., 2014a, 2014b; Martínez-rojas et al., 2016; Rezgui et al., 2011), make up the major challenges deterring the construction sector from leveraging smart, state-of-the-art technologies. Building Information Modeling (BIM) is the most optimal solution for the mobilization of the construction sector to the extent that is comparable to other related industries. BIM has played a pivotal role in the recent paradigm shift that emerged in the construction sector. BIM is a tool capable of digitally representing the physical and functional characteristics of buildings, systems, and components that positively contribute to the life cycle management of construction projects (Eastman, 1999; Popov et al., 2010; Sacks et al., 2008). Moreover, BIM provides a multidisciplinary environment wherein all project participants collaborate on a common platform, thereby simplifying the decision-making process and facilitating a collaborative and real-time decision-making culture (Benjaoran, 2009; Fu et al., 2006; Vanlande et al., 2008), (Fu et al., 2006). The BIM platform is an information repository equipped with the functions required to support construction managers in their decision-making process, enhancing the efficiency and effectiveness of the projects.

The use of predictive and smart techniques in the BIM platform can be considered in the context of the decision-making process in the construction environment. Predictive decision-making includes complex functions and their optimization and evidence-based decision modeling, heavily depending on the reliability and accuracy of data (Wang et al., 2020). Predictive decision-making methods act as tools to minimize the gap between the known and the unknown. Incorporating predictive techniques can make the construction management decision-making processes more efficient and reliable. Prior to the development of BIM, there was an absence of a reliable basis capable of supporting predictive decision-making in construction. BIM can store physical and functional data using its multi-dimensional nature along with geometry (3D), schedule (4D), cost (5D), operation (6D), sustainability (7D), and safety (8D), which enables the extraction of project-specific data for further analysis and prediction when there are multiple dimensions within a project (Azhar et al., 2008; Hardin, 2009; Kymmell, 2008; Latiffi et al., 2014; Sebastian, 2011). There has been a growing interest in the use of BIM for schedule management, cost management, safety management, and quality management in the AEC industry (Azhar et al., 2008; Latiffi et al., 2014). Currently, research pertaining to the numerous capabilities of BIM is highly dispersed; there is a need to merge them and identify innovative research, particularly in the context of construction management.

There is no dearth of review articles focusing on BIM adaptation in the construction sector, with scholars focusing on different contexts underlying this industry. Evaluations of building sustainability (Ansah et al., 2019; Ayman et al., 2020; Chang & Hsieh, 2020; Kwok et al., 2019; Lu et al., 2017; Santos et al., 2019), building fire safety (Davidson & Gales, 2021), automation of code checking process (Ismail, 2017), are some of the common themes touched upon in literature review papers. Furthermore, efforts are being made by the researchers to further explore the possibility of BIM adoption in the construction industry (Eadie et al., 2013; Smith, 2014) along with BIM-based site collaboration (Liu et al., 2017; Oraee et al., 2017), and specific management practices related to BIM (Wong et al., 2014). Hence, the need for a critical review of BIM-based construction management decision-making is glaringly evident to pave the way for future researchers.

The objective of this paper is to critically review BIM-based platforms as tools for predictive decision-making in construction management. This review was performed based on four challenges plaguing construction management: schedule, cost, quality, and safety management. In this review, several contemporary BIM-based solutions were identified to offset these challenges. The knowledge derived from this extensive review was utilized to devise a strategical roadmap to support predictive decision-making in construction projects. This map discusses how BIM can support predictive decision-making in key stages of a project life cycle, i.e., conceptual development, design, procurement, and construction. The findings of this research aim to inform construction management researchers and assist them in their future research. Among the far-reaching benefits of predictive decision-making are reduced schedule delays, project cost reduction, and improved project quality and safety. Thus, the construction industry will also benefit from the potential strategies outlined in this paper.

Methodology

Keyword search in academic databases has been a popular research method used in several review studies (Lin & Shen, 2007; Xue et al., 2010; Zheng et al., 2013). In this study, the literature search was conducted across the Scopus Engineering Village and Google Scholar databases, which are among the most prominent and extensively utilized research databases renowned for their wide range of coverage. As a first step of the study, a rigorous search was conducted using the database's title/abstract/keyword field. The study utilized various keyword combinations during this process (e.g., BIM, schedule, cost, construction safety, quality management, and construction) and employed journal articles, conference proceedings, books, and book chapters that were published in English for the bibliometric review process. The journal articles published from 1974 to 2021 were chosen as a filtering criterion. Any articles published prior to 1974 were omitted since BIM is a concept that has been extensively researched only in the last couple of decades. Finally, a content analysis was conducted against the abstracts of the filtered journal articles, and 385 articles were shortlisted due to their potential relevance to the present study. Finally, after a detailed content analysis of the 385 articles, 175 were chosen for the present review. These articles were reviewed to identify BIM-based construction management strategies. Table 1 presents a summary of published literature on this subject domain.

Construction management challenges

Schedule management challenges

To create a schedule, a wide range of information is necessary, although the final schedule does not explain the process and assumptions behind the activity sequences (Aredah et al., 2019). To devise an effective schedule, details, such as resource and equipment allocation, time–cost trade-offs, constructability issues, and optimum productivity, should be taken into account (Koo & Fischer, 2000). The precision of a project schedule may vary based on the construction manager's experience and knowledge (Cherneff et al., 1991). A project planner is important to the process of construction since it determines the sequence of construction activities enabling the efficient allocation of resources and the effective use of limited site spaces. Currently, construction management decision-making is performed through reliance on prior experience that drives the analogous, parametric, and triple-point scheduling mechanisms. When decision-making is informed by prior experience, some challenges faced include the handling of a large volume of schedule information and the inability to perform detailed analysis for different scenarios (e.g., what-if analysis) from the data acquired

Table 1 Summary of the published literature

Construction management aspects	Total number of articles	2014 and before	2015	2016	2017	2018	2019	2020	2021
Schedule management	23	2	4	2	1	2	6	4	2
Cost management	27	7	3	3	2	1	2	6	3
Safety management	70	28	10	8	4	5	4	6	5
Quality management	55	14	7	3	6	11	7	5	2
Total	175	51	24	16	13	19	19	21	12

from the repositories and experts (Behzadan et al., 2015). The scheduling tools that are in use today require complex and time-consuming data entry to reflect the changes incorporated (Davis et al., 1974). Furthermore, the final schedule should be synchronized with all project participants and must take into account any potential uncertainty to make it more accurate (Davis et al., 1974). Traditional scheduling methods are error-prone and could be daunting in these instances (Martínez-rojas et al., 2016).

Cost management challenges

Cost estimators use historical cost data and market trends to estimate project costs (Chou, 2011). The cost estimation challenges are similar to the aforementioned challenges in the schedule management section. In addition, data limitations, lack of proper data management, repository maintenance and handling, and incorporation of cost uncertainties further complicate the process (Baloi & Price, 2003; Ji et al., 2011a, 2011b; Lawrence et al., 2014; Staub-french et al., 2002). Other hurdles for cost management include poor site management, information delays, changes in scope, aggressive competition, slow decision-making due to its isolated nature, and the usage of traditional cost accounting methods and software (Iyer & Jha, 2005; Shane et al., 2009; Trost et al., 2003; Williams & Gong, 2014). Traditional estimating software links elements from a building design to cost items listed in a cost database. However, to optimize project costs, the cost estimation process must also consider the estimator's rationale. However, traditional estimating methods lack the functionalities to interlink the estimator's rationale and the design and cost information. Complexities in modern construction include excessive design changes as dictated by client requirements, which lead to project cost overruns. Therefore, there is a need for automated technology capable of storing and using the estimator's rationale to incorporate any potential uncertainties (Timberline, 2001).

Safety management challenges

Safety incidents adversely affect project efficiency and the economy (Zhang et al., 2013). For effective safety management, potential hazards and risks must be determined. Hazard identification can commence from pre-construction and span throughout the operational stage (). However, hazard identification is not devoid of challenges ranging from inaccurate data sharing among project participants to decision-making based on uncertain information, as well as non-standard procedures and unorganized tasks (Martínez-Rojas et al., 2018; Zhang et al., 2013). Identifying the cause-effect relationship for safety incidents will provide a plausible basis for safety management (Zhang et al., 2013). Historical data-based accidents analysis presents generic data for identifying trends and causes underlying safety incidents in the construction sector and incorporates or suggests potential remedies to decision-makers to enhance project safety. Therefore, it becomes possible to implement preventive measures to avoid or reduce the impacts of safety incidents (Han et al., 2014).

Quality management challenges

Construction quality management is an umbrella term used to refer to control measures that avoid defects, errors, rework, and failure (Mills et al., 2009). Quality issues in construction projects result in cost overrun, time overrun, loss of potential business to the organization, and non-conformance to requirements (Chin et al., 2004). Construction quality issues may arise due to multiple reasons, such as documentation errors (Cusack, 1992), poor managerial practices (Rounce, 1998), construction error, change and omission, and poor workmanship and materials (Construction Industry Institute, 2003). Quality management is a data-intensive process. Traditional methods utilize data gathered from on-site inspection and regulation, wherein managers manually record paper-based documents, leading to inefficient management. Thus, similar to the previous sections, predictive decision-making methods and automated data capturing and monitoring are necessary to avoid defects in construction projects. Figure 1 summarizes the above-mentioned challenges in construction management pertaining to schedule, cost, safety, and quality management aspects.

Predictive decision-making

Industries and organizations around the world are incorporating predictive decision-making methods to enhance the economy and productivity of organizational operations (Doloi, 2013). Predictive decision-making includes complex functions, optimization, and evidence-based decision modeling, significantly depending on the reliability and accuracy of data (Wang et al., 2020). This approach has emerged from data science, where it identifies patterns in big data to forecast any uncertainties and risks. Moreover, the potential implications of decisions must also be analyzed to optimize the solution (Mosavi et al., 2018).

Predictive decision-making is helpful in construction projects that require handling large amounts of data with several conflicting attributes (Jato-espino et al., 2014). This mechanism aids managers in analyzing complex scenarios and enables them to undertake appropriate precautions prior to the commencement of a project (proactive approach as opposed to a conventional corrective approach) (Dziadosz & Konczak, 2016). For example,

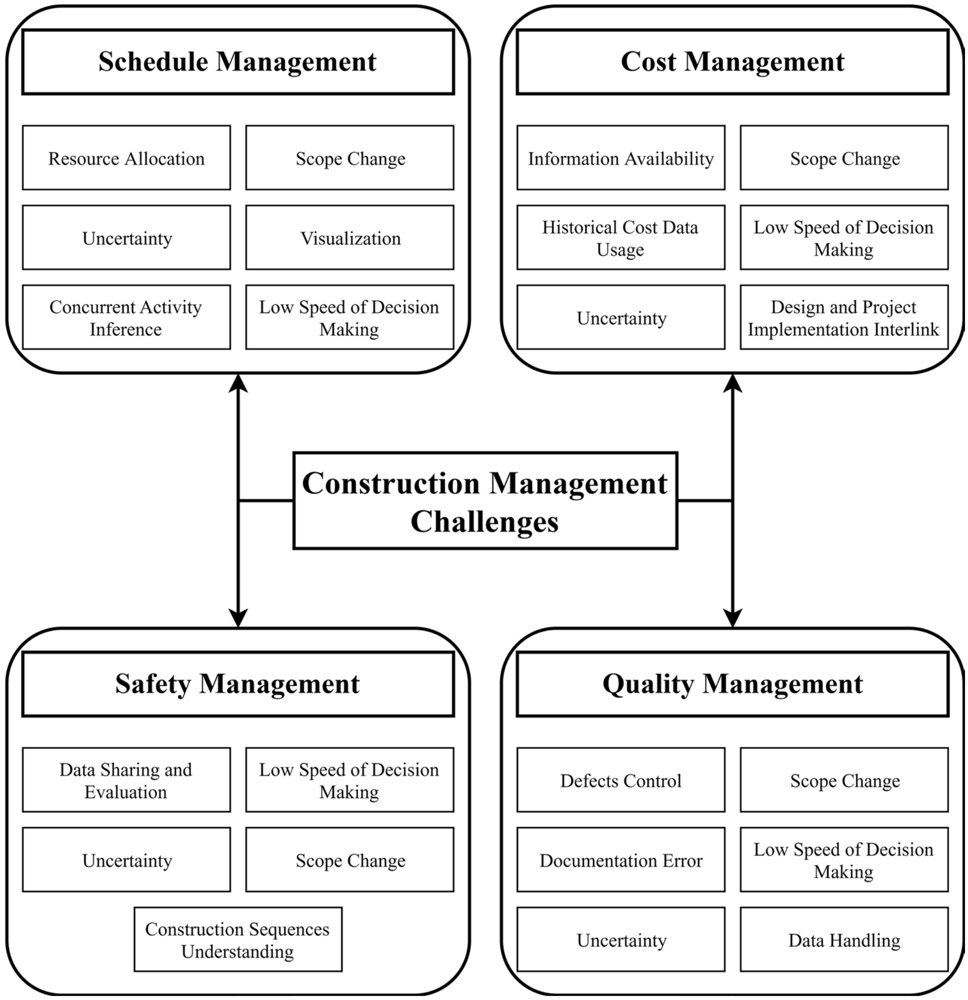

Fig. 1 Construction management challenges

predictive decision-making is a handy mechanism that can help with on-time project completion without exceeding the planned budget (Mohamed et al., 2009). The application of the predictive decision models increases the accuracy of estimates at the pre-project planning stage. This accuracy, in turn, facilitates the completion of construction projects under the predetermined cost and time baselines (PASC, 2020).

Decision-tree is a basic predictive decision support method that summarizes the potential events that could unfold due to a specific decision. Joshi employed a decision tree to analyze the labor productivity in construction projects (Joshi, 2010). In certain other projects, expert systems were used by some investigators as another predictive decision-making method (Bryant, 2009a). Some expert systems utilize Case-based Reasoning (CBR), which is an AI-based approach with a knowledge base containing information from real-world cases to imbibe the skills required to manage novel situations (Zhu, 2013). Among the most common methods adopted in CBR is Monte Carlo simulation (Kumar & Viswanadham, 2007). Conversely, some expert systems use Rule-based Reasoning (RBR), which defines a set of connected rules that lead to a given conclusion. This knowledge is most commonly represented with the assistance of "if–then" rules (Bryant, 2009b). Two of the most common RBR methods are the Fuzzy Inference System (FIS) and Adaptive neuro-fuzzy inference system (ANFIS). However, AI, Bayesian methods, and Neural Networks are also used for construction-based decision-making, although they are yet to be adopted on a larger scale.

BIM for predictive decision-making in construction management

As a repository of project life cycle data, BIM can be an effective tool in executing predictive decision-making (Lam et al., 2010; Wells, 1985). In the following sections, various methods used for BIM-based decision-making in construction management are discussed.

BIM-based schedule management

BIM-based schedule management is gaining significant traction today (Aredah et al., 2019; Curry et al., 2013; Liu et al., 2015; Moon et al., 2015; Song et al., 2012; Wang, 2019; Wang & Song, 2016). The Fourth Dimension (4D) of Building Information Modeling is a characteristic of BIM-based schedule management technology that is built on the information embedded in the model. Schedule management can model and analyze sequencing activities within a construction schedule with respect to time and space. In the domain of BIM-based schedule management, previous researchers have focused on the following three areas: i) minimizing schedule overlap and delay, ii) automated scheduling, and iii) detection of errors and missing data.

Overlaps in activities and potential delays in a construction site lead to changes in the project timeline and schedule. If specific project activities are delayed, it can risk deferring the completion date of the entire project (Dehghan & Ruwanpura, 2011). Overlapping tasks may emerge in both highly intricate project schedules as well as high-level summary schedules. Moon et al. developed an active construction schedule management system by integrating BIM with fuzzy-based risk analysis algorithms and genetic algorithms (Moon et al., 2015). This method was used to create an optimal schedule with minimum overlaps. Management of a construction project in the design and execution phase heavily depends on easy access to data (Chassiakos & Sakellaropoulos, 2008; Lu et al., 2014a, 2014b). The integration of BIM and GIS is of great significance in the geospatial section because of the rising research interest in smart cities, Internet-of-Things, and urbanization (Deng et al., 2019a, 2019b). Bansal and Pal's early attempts at 4D visualization of construction sequence were carried out by linking GIS and project schedule with a 3D model of the project (Dehghan & Ruwanpura, 2011; Wang & Song, 2016). This process informed and educated less experienced project participants about what must be built and its scheduled time and location of installation. Irizarry and Karan integrated BIM and GIS to determine the optimal locations of tower cranes. Through this research, they solved the problem of identifying optimal locations for a minimal number of tower cranes to eliminate potential conflicts in the schedule (Irizarry & Karan, 2012).

Furthermore, Wilfredo et al. have conducted a study on a machine learning method used to parse descriptions and spatial time-phased data of a construction project, which were then animated with visual cues (Amir et al., 2019). This research may be viewed as an extension of 4D simulation with a large amount of data embedded for higher accuracy with information associated with activity, relationships, lags, and leads. However, the proposed method is a time-intensive process at earlier stages when data is mined from existing projects. In addition, it requires the development of a database in a standard format that can be automatically identified by a computer program.

Chen and Tang proposed a workflow design integrating BIM and digital programming to address schedule and cost uncertainties during the maintenance stage, which can prevent delays in building maintenance (Chen & Tang, 2019). Chen and Nguyen integrated BIM and Web Map Services (WMS) to simplify and optimize construction material selection (Chen & Nguyen, 2019). This approach provided substantial data related to material, such as sources or vendors, storage locations, availability, costs, and transportation methods that help the project team estimate the final cost and delivery time of the material to guarantee optimal inventory and timely delivery of materials. Integration of semantic web with BIM and GIS can assist the construction manager in improving access to data, eliminating paperwork, recording data in a multimedia format, removing inaccuracies in the documents, and improving collaboration among the project participants (Chassiakos & Sakellaropoulos, 2008). This approach reduces delays and extensive costs associated with traditional document management.

Automated scheduling has been a key domain in BIM-based schedule management research. The estimation of an activity duration is a challenge in the pre-construction stage. Accurate activity duration directly correlates with projecting management experience. Mikulakova et al. proposed a knowledge-based system for automated schedule generation (Mikulakova et al., 2010). This method combined BIM and construction processes with past data from successfully executed projects to determine the project duration (Mikulakova et al., 2010). Developing such knowledge-based systems for predicting work task durations has been a growing domain of research in the recent past (Elwakil & Zayed, 2012). A study conducted by Hexu et al. recommended an automated scheduling approach using an add-on to Autodesk Revit (Liu et al., 2015). The algorithm can define the optimal activity duration considering the attributes of the project and user-defined constraints on different activities. Getuli and Capone developed an ontology-based automatic scheduling system in the BIM platform that utilized construction scheduling knowledge as a foundation (Getuli & Capone, 2019). Knowledge-based scheduling ontology enhanced the semantic representation and efficiency of supporting processes in construction schedules (Getuli, 2020).

Moreover, Wang and Rezazadeh proposed a BIM-based framework to create project schedules of concrete-framed buildings. This method leverages prior knowledge to devise rules after considering building objects and their attributes and then generates a list of work packages, their duration, and sequences (Ziwei Wang, 2019). Li et al. applied BIM and Radio Frequency Identification Device (RFID) to enhance coordination between project stakeholders. This method analyzed the critical schedule risk factors and developed an automated RFID-enabled BIM platform that integrates various stakeholders and information flow to manage risk factors. This research attempted to ensure timely project completion in prefabricated housing construction by addressing schedule risks (Li et al., 2017). Cheng and Chang presented an optimization model for BIM-based site material layout planning (Cheng & Chang, 2019). This method addressed delays in logistics and enhanced the efficiency of construction.

Even though hundreds of studies are being conducted on project schedule management and BIM, only 30%-40% of companies are enjoying its benefits (Amir et al., 2019). The perception toward BIM, availability of practical applications, costs of implementation, and longer learning curves are major drawbacks deterring companies from implementing it. Studies pertaining to complex algorithms, such as machine learning, AI, etc., require large databases related to construction activities. This would be practical only if integrated with a sensor network and a real-time data monitoring platform, which is complex, expensive, and varies with local decision-making approaches. Refer to Table 2 in Appendix for an overview of published literature on BIM-based schedule management.

BIM-based cost management

A fully integrated BIM environment combined with cost estimation software, also known as the Level 03 BIM platform for embedding cost dimension (5D BIM), is an ideal solution for cost management in AEC projects (Eastman et al., 2011). Previous BIM-based cost management research entails three key research areas: i) automated cost estimation and prediction, ii) cost optimization, and iii) Financial risk management.

Automated cost estimation has been the most popular area of research in BIM-based cost estimations. Zhiliang et al. proposed an Industry Foundation Class (IFC)-based model for estimating construction costs. The extended IFC standards presented in this study provide division-item property sets, cost items, and mathematical relationships (Zhiliang et al., 2011). Lee et al. proposed an automated work item searching system developed through the integration of BIM with an ontological inference process. The proposed approach assists cost estimators in employing BIM data to find work items and their quantities. Moreover, it eliminates the need for the intervention of the cost estimator's subjectivity (Lee et al., 2014). Xu et al. proposed a framework by integrating BIM with semantic web ontology and forward chain algorithm to establish new means of obtaining and deriving data from a BIM model. Such data was used for developing the essential items to perform the quantity take-off. The proposed framework helps the AEC industry with the development of an automated cost estimation system (Xu et al., 2016). Cheung et al. proposed a BIM-based cost estimation module to assess different aspects of building design in the early design stages. The multi-level cost estimation tool presented in this study enables users to automatically obtain measurements from 30 models and evaluate the functionality, economics, and performance of buildings (Cheung et al., 2012). Lawrence et al. integrated BIM with query language to propose a generic approach for creating and updating a cost estimate. The outcome of this approach adds flexibility to cost estimation and enables the estimator to encode a wide variety of relationships between the design and the estimate (Lawrence et al., 2014). Niknam and Karshenas integrated BIM and semantic web service technologies, as well as ontology inference processes to improve the accuracy of cost estimation (Niknam & Karshenas, 2015). Wang et al. proposed a method that utilizes BIM and cost-based progress curves to identify construction progress curves (Wang et al., 2016). This method identifies take-off objects to obtain quantities of cost items related to each activity. This study shows that this method can prevent errors that emerge when manually typing cost-item names (Wang et al., 2016).

Cost optimization leads to more profits with acceptable quality, safety, and schedule in AEC projects. Further, cost optimization ensures that the cost of construction does not exceed the budget and maximizes the profit in the design stages (Rajguru, 2016). Traditional cost accounting methods are often inaccurate and inefficient since the design undergoes frequent changes in the early phases. A study conducted by Pathirage et al. entailed the development of a BIM-based method to highlight change orders and minimize project costs (Pathirage & Underwood, 2015). Faghihi et al. proposed a cost optimization method based on the integration of BIM with Pareto Front analysis. This study presented a tool to help project managers to optimize project cost and scheduling (Faghihi et al., 2016). Eleftheriadis et al. integrated BIM with Genetic Algorithm (GA) and Finite Element Modeling (FEM) to develop a cost optimization approach and embodied carbon of reinforced concrete structures. This approach enables managers to make early design decisions considering the costs and environmental implications (Eleftheriadis et al., 2018). He et al. developed a five-dimensional construction cost optimization model by integrating BIM with GA. The proposed system provides solutions for managers to prevent cost and time overruns in construction projects (He et al., 2019).

Proper financial risk management is crucial for project success since it is meant to ensure that the project does not exceed the budget (Cooke, 1996). According to a study conducted by Huang, unforeseen costs can be reduced from 50 to 15% using BIM. Risk factors due to uncertainty and the inability to visualize the project are mainly addressed through the proposed approach (Huang, 2021). The literature reveals that Cha and Lee proposed a BIM-based framework to identify work items in construction sites and the relationships among activities to reduce human error and increase work efficiency (Cha & Lee, 2015). Sun et al. proposed a project cost and schedule risk early warning model by integrating BIM with Earned Value Analysis (EVA). This study also addresses the problems and challenges of traditional EVA methods that rely on the experience of project participants in construction management (Sun et al., 2015). Shan et al. developed a BIM-based approach for cost management across the processes in high-risk construction projects. This research proposes the reduction of pipeline clashes, reworks, and project costs as potential solutions to minimize the risk of high-risk AEC projects (Shan et al., 2018).

Reviewing BIM-based cost management literature revealed that automated cost estimation has begun to garner more attention in the recent past. Automated cost estimation increases the speed and accuracy of cost prediction (Mittas et al., 2015). BIM-based cost management offers many advantages, such as advanced and automated quantity take-off for cost estimation in highly dynamic environments, estimation based on big data, optimum output choices from different scenarios, and web-based collaboration. However, according to the literature, several challenges continue to deter the implementation of BIM, such as the inability to utilize the software tools to their maximum capacity, cost of implementation, as well as a hindrance in data sharing. Refer to Table 3 in Appendix for an overview of published literature on BIM-based cost management.

BIM-based safety management

Previous research on BIM-supported safety management has focused on (i) enhancing on-site communication, (ii) construction hazard detection, and (iii) safety planning in AEC projects (Zhang & Hu, 2011). BIM supports communication and collaboration, enabling the project teams to share their knowledge and propose safety improvements throughout the project life cycle (Martínez-aires et al., 2018; Zhou et al., 2012). Dossick et al. investigated the role of BIM in augmenting coordination and collaboration in a construction project (Dossick et al., 2010). This study concluded that BIM is necessary to navigate a complex project hierarchy with a large volume of data and facilitate information exchange between project participants. Ganah and John suggested adopting BIM in toolbox talks (Ganah & John, 2015). The BIM-based visual aid will enhance the effectiveness of safety hazard identification and the team's communication and collaboration. Lin et al. developed a BIM-based intelligent productivity and safety system to aid project stakeholders with the collaborative assessment of the safety performance prior to the project commencement (Teo et al., 2017). Golparvar-Fard et al. proposed the integration of BIM and 4-Dimensional Augment Reality (AR) to present a better visualization of construction operations and their sequences. The authors revealed that this model could provide easy-to-understand and detailed attributes for remote project monitoring (Golparvar-fard et al., 2011). Le and Hsing integrated BIM with a mobile web map service and GIS coordinates to support data exchange in real-time and manage any risks to adjacent buildings and the neighborhood (Le & Hsiung, 2014). Nawari integrated BIM with the Information Delivery Manual (IDM) to resolve problems associated with augmenting the national BIM standard to facilitate more reliable data exchange between project participants, which enhances information quality and ensures prompt communication (Nawari, 2012). Niu et al. presented a BIM-based framework for augmenting construction resources with technologies concerning autonomy, awareness, and the ability to interact with their vicinity to function as smart construction objects. The proposed method enables a safer, greener, more efficient, and more effective construction system (Niu et al., 2016). Park and Kim integrated BIM with AR, location tracking, and a game engine to improve the real-time collaboration between managers and workers. This method helps project safety managers monitor their workers in a safe manner during the construction phase of projects (Park & Kim, 2013). Getuli et al. implemented a BIM and VR-based safety training protocol and safety-oriented planning approach for the construction industry, further enhancing BIM utilization in the safety management process (Getuli et al., 2020a, 2020b). Chen et al. improved and augmented fire safety and safety upskilling through the integration of BIM, the Internet-of-Things, and AR/VR technologies (Chen et al., 2021). Ciribini et al. developed a 4D BIM-based interoperable procedure to conduct safety-based code checking and analyze the construction phase. This proposed process enables managers to ensure construction worker safety (Ciribini et al., 2016).

Identification of causality of project hazards can help with enhancing site safety (Zhang et al., 2015b). Researchers are now focusing on detecting project hazards with BIM. Safety management of a project should be considered starting from the conceptual and design stages to identify and minimize risk factors that would persist throughout the lifecycle. Malekitabar et al. detected more than 40% of potential fatalities in construction projects through five sets of safety risk drivers as construction incident sub-causes to help managers. These safety risk sub-causes can be derived from a BIM model (Malekitabar et al., 2016). BIM has been an effective method for safety management in confined workspaces. Moon et al. developed a BIM-based methodology to identify scheduling and work-space conflict (Moon et al., 2014a). Park et al. used BIM with Bluetooth Low-Energy (BLE)-based location detection to identify unsafe conditions and analyze labor routes by taking into account potential safety hazards. Chavada et al. used BIM in conjunction with the Critical Path Method (CPM) to accurately manage workspaces on construction sites and prevent workplace incidents (Chavada et al., 2012). In the above study, the integrated system enables safety managers to monitor construction workers and prevent safety incidents using BIM-supported decision-making platforms (Jeewoong Park et al., 2017) and allows construction managers to undertake preventive measures during the pre-construction stage (Qi et al., 2014a).

Furthermore, several researchers have used BIM as the data domain to perform safety checks. Qi et al. and Zhang et al. proposed BIM-based methods to check fall hazards (Qi et al., 2014b; Zhang et al., 2015b). Within this context, BIM was integrated with other technologies, such as real-time locating systems, wireless sensing, and real-time audio warning for safety-focused applications. Wang et al. used BIM with range point cloud data to detect fall hazards in geotechnical projects (Wang et al., 2015a, 2015b). Protective measures for falls were proposed upon identifying the fall hazards. Akula et al. presented a method based on the integration of BIM with 3D imaging technologies to identify safety hazards when placing embeds into existing reinforced concrete structures (Akula et al., 2013). Ding et al. used BIM and semantic web technology to model construction risk and develop risk responses. This framework produced a risk map and recommended a risk prevention plan (Ding et al., 2016). Golovina et al. investigated hazard causes related to construction equipment and proposed a GPS and BIM-based method for recording, detecting, and analyzing interactive, hazardous near-miss situations between workers on foot and heavy construction equipment (Golovina et al., 2016). Hu et al. presented a BIM-based framework to detect construction collisions for site entities (Hu et al., 2010a). This algorithm used boundary representation (B-rep) to detect collisions (Hu et al., 2010a). Hu et al. developed a 4D BIM model that provides comprehensive information on dynamic connections between scaffolding systems and the construction process (Hu et al., 2010b). This model was used to analyze the safety of scaffolding and worker behaviors (Hu et al., 2010b). Mihic et al. linked BIM with a construction hazards database for early hazard detection (Mihić et al., 2018). Bannier et al. proposed a BIM-based approach to address the safety challenges associated with limited work-space for piping and steel trades crews (Bannier & Goodrum, 2016). Kim et al. prepared a query set for a BIM model that automatically identifies similar accidents using a project management information system (Kim et al., 2015). Kim et al. integrated BIM with automated data collection and a real-time locating system to reduce the labor exposure time to hazards (Kim et al., 2016a, 2016b). Proactive Behavior-Based Safety (PBBS) is the combination of traditional behavior-based safety management with the Proactive Construction Management System (PCMS). This method enables managers to identify potential causes of unsafe behaviors at the execution stages before an accident occurs by automatically monitoring location-based worker behaviors (Li et al., 2015). Li et al. extended the above study to include PBBS for a BIM model to automatically monitor location-based behaviors, identify the primary causes of unsafe behaviors, and enhance the safety of the construction project (Li et al., 2015). Luo et al. developed a BIM-based method to check the code compliance of the high-risk deep foundation construction projects (Luo & Gong, 2015). Riaz et al. linked BIM and wireless sensors to monitor workers working in confined spaces. The proposed system reduces the safety risk for workers in confined spaces (Riaz et al., 2014). Zhang et al. integrated BIM and GPS to identify and visualize potentially congested workspaces to prevent suffocation hazards for workers (Zhang et al., 2015c).

In addition to the aforementioned studies, many researchers attempted to integrate BIM and Unmanned Aerial Vehicle (UAV) to track worker behaviors in mega construction sites. Teizer et al. used BIM with UAVs and laser scanning technology to automatically track construction workers and identify and prevent potential hazards (Teizer, 2015). Liu et al. employed BIM and UAV technology to enhance the level of safety inspection during the construction phase to enhance site safety (Liu et al., 2019). Cheung et al. developed a system to monitor the safety status via a spatial-colored interface and automatically remove any hazardous gas from the construction site based on the integration of BIM with a wireless sensor network (Cheung et al., 2018). This system uses wireless sensor nodes placed on underground construction sites to collect hazardous gas levels.

The third major area of research in this context is safety management through safety-focused planning and scheduling of the project, which can be considered at the planning stages of the project. Project safety can be enhanced through simulation-based scheduling and planning (Andradóttir et al., 1997). Moon et al. integrated BIM with a genetic algorithm to develop an active simulation for minimizing the simultaneous interference level of the schedule-work-space (Moon et al., 2014b). This approach aids managers in solving schedule-work-space interference and preventing safety hazards. Zhang and Hu proposed a BIM-based framework to analyze conflicts and structural safety problems during the planning stage of the project. They argued that this machine is capable of preventing safety issues and accidents from occurring during the construction phase of the project (Zhang & Hu, 2011). Similarly, Bansal et al. utilized information from the GIS-based activity database in a 4D BIM model to detect safety-based logical errors in the construction phase (Bansal & Pal, 2014). Zheng et al. proposed an ontology-based semantic BIM modeling to promote holistic inquiry of safety knowledge. With its automated safety planning for the analysis of construction site hazards, this system can efficiently prevent workplace safety incidents (Zhang et al., 2015a). Choi et al. proposed a BIM-based framework to handle space planning in pre-construction management. This research proposed a decision support tool to resolve safety issues related to workers in construction sites (Choi et al., 2014a). Mirhadi et al. developed a tool that enables designers to optimize the building layout that supports occupant safety during evacuation (Mirahadi et al., 2019). Similarly, Marzouk and Daour proposed using BIM to simulate evacuation routes for laborers during an emergency (Marzouk & Al Daour, 2018).

Attempts to analyze the fire risk of buildings during the design stage with the help of BIM is a new domain that scholars have been focusing on. Code compliance, fire risk assessment with BIM-based coding applications (Ex- Dynamo, C+, Python, etc.), and plug-ins were created to identify potential risks in the designs and minimize such iterations to ensure the safety of construction (Kincelova et al., 2020; Zhang, 2020). Rania Wehbe et al. developed a mobile app-based evacuation system to respond to fire hazards in a building (Wehbe & Shahrour, 2021). This solution integrated fire spread models and an optimum evacuation path for a safe exit from a building. Most fire and BIM-related researchers have focused on safety issue identification during the design phases of a building.

Based on the above review, it is clear that most studies have focused on the improvement of the health and safety of construction workers, while a few studies deal with resident safety. Many studies continue to focus on the operational stage of a building or the full building life cycle. A significant proportion of previous research has focused on hazard detection. Some studies presented preventive methods in the planning stage, while some others have developed a system for monitoring workers during the construction phase. Table 4 in the Appendix summarizes the published literature on BIM-based strategies used for safety management in construction projects.

BIM-based quality management

BIM-based quality management primarily focuses on three research domains: (i) Lean construction, (ii) Collaboration and communication improvement, and (iii) Automated progress monitoring. BIM is effective in implementing modern management techniques, such as lean construction to reduce defects, clashes, and wastage of time during construction projects (Chassiakos & Sakellaropoulos, 2008; Forcada et al., 2007). Sheikhkhoshkar et al. proposed automated and cost-effective planning to resolve the problem of the conventional construction joint design process (Sheikhkhoshkar et al., 2019). Porwal et al. proposed a BIM-based method for estimating construction waste from change orders. This method can help reduce construction waste by 25% (Porwal et al., 2020). Kim et al. developed a BIM-based framework for estimating demolition wastes in the design phase (Kim et al., 2017). This method estimates the C&D waste generation and waste management costs and provides data for recycling practices, environmental impact assessment, and disaster preparedness.

BIM-based defect identification and management have been frequently researched in the past. Technologies, such as digital twins, AR, and image-matching, have been integrated with BIM to support clash detection and defect identification. Park et al. proposed a framework based on the integration of BIM with AR and an ontology-based data collection template to decrease defects occurring during the construction process (Park et al., 2013). Kwon et al. presented a method that integrated BIM with image-matching and AR to identify omissions and errors at real job sites to enhance defect management (Kwon et al., 2014). Lin et al. presented a methodology that integrated BIM and web-based technology to help site managers track and manage defects. The results of this study showed that the proposed method supports effective visual defect management (Lin et al., 2016). Lin et al. proposed an approach based on the integration of BIM with the trapezoid structural transfer layer to detect collisions, optimize the construction process, and enhance project quality control (Lin et al., 2017). Lin proposed the integration of BIM with web-based systems to facilitate the updating and transferring of data in the

BIM environment. This method aids users in mitigating defects during the pre-construction phase (Lin, 2015). Hamledari et al. developed a technique to automatically transfer site data (based on site observation for inspected building elements) to the BIM model. This system identifies discrepancies between the as-built and as-designed object conditions; therefore, it can assist with defect management (Hamledari et al., 2018). Elbeltagi and Dawood employed the integration of BIM with GIS to develop a method that can evaluate and visualize construction performance against time. The proposed method reduces potential defects of repetitive actions during the decision-making process (Elbeltagi & Dawood, 2011). Park et al. proposed a method for automated registration of daily photos to 4D BIM, which helps identify BIM objects associated with corresponding photos to understand the contents and context (Park et al., 2018). Biagini et al. used laser scanning and BIM for construction management in historical building restoration projects by reconstructing a digital twin of the building (Biagini et al., 2016). The proposed method supports the preservation of historical buildings.

Facilitating seamless collaboration and communication among project participants enhances the project synergies while advancing the quality management process. Kubicki et al. integrated BIM with Smart White Board systems to create synchronous interactive devices to enhance coordination between project participants. It promotes better engagement of team members to make project decisions after considering multi-stakeholder concerns (Kubicki et al., 2019). Chen and Lu developed a BIM-based method for improving information quantity, quality, and accessibility (Chen & Lu, 2019). The results demonstrated improved data exchange between project participants. Lin and Yang developed a BIM-based collaboration management method to reduce the time required to complete the model checking process. The case study results indicate the potential held by the proposed approaches in collaborative BIM model creation for general contractors (Lin & Yang, 2018). Ma et al. used BIM with indoor positioning technology to resolve the omission of check items and initiate the process of digitizing inspection results. The outcomes of this study demonstrated the improvement of collaboration among the construction stakeholders (Ma et al., 2018). Oh et al. presented a BIM-based integrated system to aid collaborative design, which addresses the challenges associated with employing various BIM-based software when collaborating during the design phase and resolving pertinent issues, such as loss of data and difficulty in communication (Oh et al., 2015). Koseoglu et al. proposed a framework based on the integration of BIM with lean construction principles (Koseoglu et al., 2018). Larsen developed a BIM-based framework to address the challenges associated with traditional progress reporting. This framework consists of three steps for minimizing manual reporting and improving communication during the reporting process (Mejlænder-larsen, 2018). Park et al. integrated BIM with web-based systems to enable real-time information sharing of daily 4D BIM. This method improves the collaborations and communications among project participants regarding daily construction operations, aiding project managers in making appropriate decisions (Jaehyun Park et al., 2017). The quality Assurance and Quality Control (QA/QC) process that is typically practiced at construction site tend to comply with designers' drawings and specifications. This process typically utilizes manual checklists. Several studies demonstrate the advantages of using mobile-based BIM to comply with lean construction practices and build quality-assured construction (Donato et al., 2018). Web and mobile-based checklists, defects, or errors in communications during QA/QC procedures illustrate success with real case projects according to the studies mentioned above.

The third approach to quality management studies is related to progress monitoring. The success of progress monitoring in a construction project depends on detailed and efficient tracking, analysis, and visualization of the actual status of buildings under construction (Golparvar-fard et al., 2015). To accomplish this, BIM has been integrated with techniques, such as GIS, UAV, RFID, AR, and laser scanning. The use of laser scanning has been a popular research topic in the recent past. Wang et al. used BIM and Laser Scanning Display (LSD) to automatically estimate the dimensions of precast concrete bridge deck panels and thus, improve the quality inspection of panels (Wang et al., 2018). Similarly, Bosché presented a method based on integrating BIM with laser scanning to automatically recognize 3D CAD model objects and calculate as-built dimensions. The results of this study showcased that this system enhances the level of quality inspection during the construction phase (Bosché, 2010). Bosche et al. used BIM with laser scanning to present automated object recognition, which indicated its potential in controlling as-built dimension calculation (Bosche et al., 2009). Bosché et al. integrated BIM with laser scanning for structural work monitoring. The proposed system provides accurate information from the construction site to improve the progress monitoring process (Bosché et al., 2014). Dimitrov and Golparvar proposed a vision-based material recognition method based on the integration of BIM with point cloud data. This method can generate a BIM model from unordered site image collections, which can significantly improve the automated monitoring of construction progress (Dimitrov

& Golparvar-fard, 2014). Han et al. developed an appearance-based recognition method using BIM with 3D point cloud models to determine construction progress (Han & Golparvar-fard, 2015). Braun et al. proposed automated progress monitoring with photogrammetric and BIM (Braun et al., 2015). The real-time point cloud of a construction project is generated through a large number of images captured by a camera. The study proposes an iterative step for construction planning from real-time progress. However, the inability to capture clear images of the whole building, the requirement of large volumes of data to build a point cloud and implementation costs remain the disadvantages of this study. Costin et al. integrated BIM with RFID to enable real-time tracking and monitoring of construction workers. This integrated method, as demonstrated by the results, can maintain building protocol control (Costin et al., 2015). Choi et al. used BIM to perform path analysis to enhance monitoring workspaces (Choi et al., 2014b). The proposed framework enhanced the work-space planning process. Shahi et al. used BIM with imaging and Ultra-Wide Band to track the progress of construction activities (Shahi et al., 2015). Braun and Borrman developed a method based on the integration of BIM with inverse photogrammetry technique to automatically label construction images. This system enhances image-based object detection, which is the basis of construction progress monitoring (Braun & Borrmann, 2019). Asadi et al. proposed a BIM-based method to facilitate as-built and as-planned data comparison. This system automatically registers real-time images to a BIM model. Therefore, it aids managers with monitoring construction work indoors (Asadi et al., 2019).

Tezel et al. studied BIM and lean construction and revealed that significantly lesser research attention had been directed toward Small and Medium Enterprises (SMEs), whose contribution to the industry is substantially greater (Tezel et al., 2020). The paper invites future scholars to further explore BIM implementation in SMEs to deliver a positive impact in the context of lean construction. Table 5 in Appendix provides an overview of BIM-based articles related to quality management.

Roadmap for BIM-based predictive construction management

Knowledge generated from this review was leveraged to develop a strategy map to support predictive decision-making in construction projects. Figure 2 illustrates the proposed strategy map and how BIM can support predictive decision-making in key stages of the project life cycle, i.e., conceptual development, design, procurement, and construction.

This roadmap indicates that a number of organizational processes are required for the proper implementation of BIM in the construction industry. These processes are (i) Investments in BIM-related software packages and training, (ii) Mandating BIM-supported planning and monitoring mechanisms for mega projects, (iii) Expanding the BIM training system to increase awareness and develop a skilled workforce, and (iv) Storage and maintenance of big databases related to construction projects, employing them to create automated decision support systems.

BIM can be integrated with multiple software and platforms. However, it is necessary to identify the exact requirement and choose the optimal software for such an integration for the project decision-making. The proposed roadmap illustrates BIM functionality in each stage of a construction project and in each section of construction management. During the conceptualization phase, BIM-based approaches, such as safety planning and scheduling, risk management, and lean construction, could help project investors, contractors, and managers to develop a more accurate visualization, class detection, finance and supply chain planning, and risk identification. Moreover, it is also possible to create multiple design alternatives with BIM computational designs, which can be compared with the base case to identify potential safety, quality, schedule, and cost issues. Subsequently, the project investors and clients can select the most desirable project based on their organizational strategies. Furthermore, this process can be augmented by integrating real-time communication with the help of the BIM model using Virtual Reality and Augmented Reality-based techniques. By creating visual models at their planned locations, this feature can help them identify any negative implications for the neighboring buildings and infrastructures. Moreover, this mechanism also comes in handy to witness the esthetic appearance of the building. Besides, as shown in the roadmap, some techniques such as GIS must be integrated with BIM to reach the aforementioned outcomes.

In the design phase, BIM aids with predictive decision-making in multiple ways. Feasibility checking and preparing contract documents are two of the issues that must be checked in the design phase. The collaboration feature of BIM helps with the accurate management of project design schedules as well as design optimization due to the rich data utilization. The proposed techniques in the roadmap assist managers with accurate cost estimation and time planning, which will not skew from the actual project cost and duration. Moreover, BIM can be integrated with expert systems to enable managers to detect hazards during the design phase and prevent

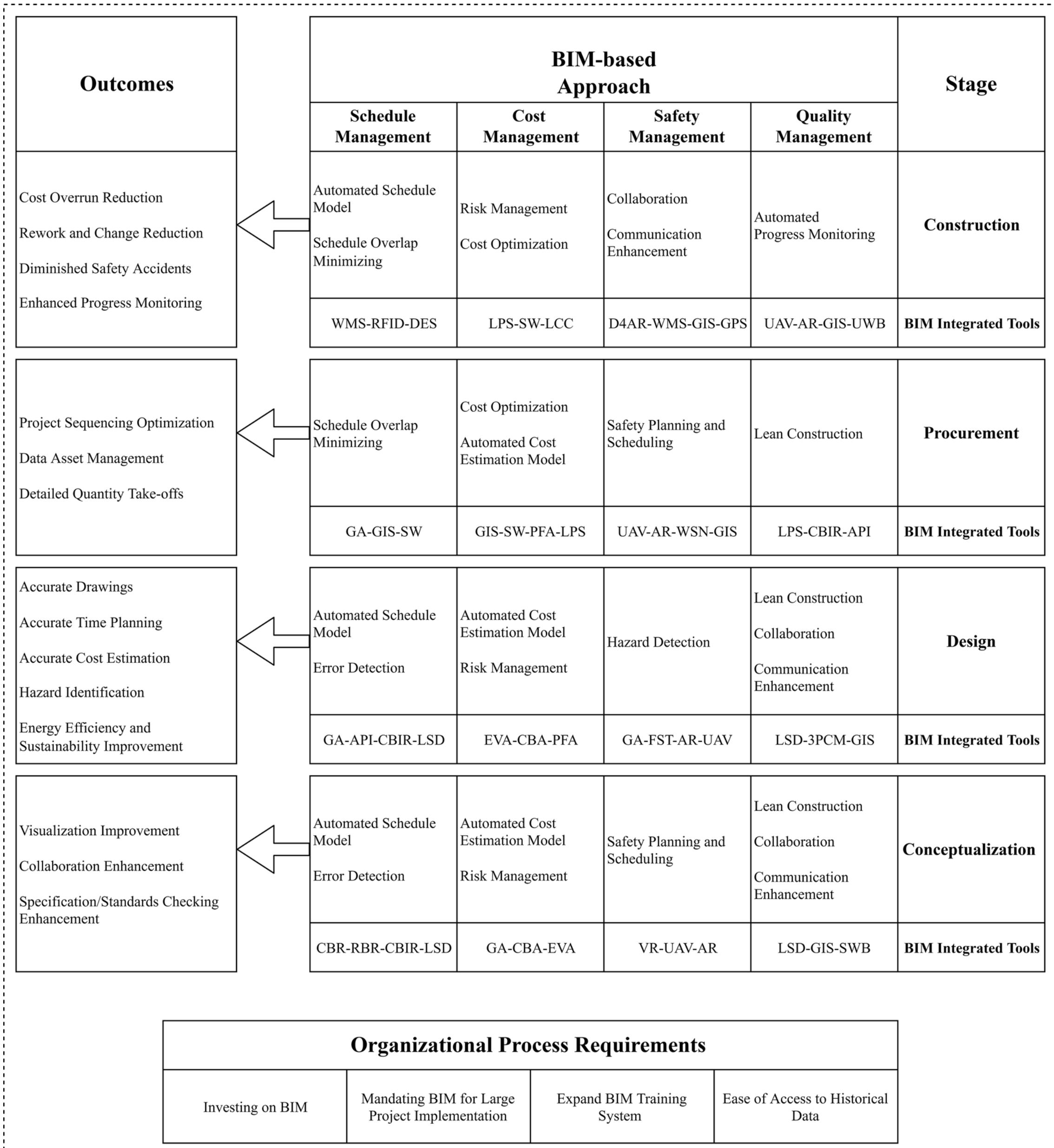

Fig. 2 Roadmap of predictive decision-making improvement. Note: API: Application Programming Interface, AR: Augmented Reality, CBA: Cost Benefit Analysis, CBIR: Content-Based Image Retrieval, CBR: Case-Based Reasoning, DES: Discrete Event Simulation, D4AR: Four-dimensional Augmented Reality, EVA: Earned Value Analysis, FST: Fuzzy Set Theory, GA: Genetic Algorithm, GIS: Geographic Information System, GPS: Global Positioning System, LCC: Life Cycle Costing, LPS: Local Positioning System, LSD: Laser Scanning Display, PFA: Pareto Front Analysis, RBR: Rule-Based Reasoning, RFID: Radio Frequency Identification Device, SW: Semantic Web, SWB: Smart Whiteboard, UAV: Unmanned Aerial Vehicle, UWB: Ultra-Wideband, VR: Virtual Reality, WMS: Web Map Service, WSN: Wireless Sensor Network, and 3PCM: 3D Point Cloud Models

accidents for both construction workers and building occupants. Better coordination of building elements, such as envelope, mechanical and electrical, etc., can be used to identify possible clashes and implement the necessary modifications to avoid potential project delays. 6D BIM also enables managers to perform energy analysis and improve sustainability performance.

In the procurement phase, BIM-based approaches such as automated schedule models enable managers to conduct accurate quantity take-offs and determine the required equipment. The required quantities of materials and equipment can be accurately calculated in the pre-construction phase of a construction project. Accordingly, contractors can purchase and order materials and equipment in a timely manner without any unnecessary delays while maintaining optimal inventory levels. Improving this mechanism will also help decision-makers to leverage lean methods such as Just in Time-based inventories for locally available materials (for long-term fix price products) and hedging mechanisms for materials with frequent price fluctuations.

The construction phase of a project benefits from BIM-based accurate progress monitoring with features of automation and web-based platforms. The quality control and assurance process can be digitalized with the aid of mobile extensions in BIM. Furthermore, a large number of stakeholders can communicate seamlessly via the same BIM environment during the construction phase. A novel approach integrates the EVA method within the BIM database. This would enhance the efficiency and effectiveness of decision-making and provide a visual platform to compare the planned development with the actual progress.

Conclusion

This study conducted a critical review to investigate how construction management researchers have adopted and employed BIM to support predictive decision-making. The research framework in this study incorporated the main construction management challenges (i.e., schedule management, cost management, safety management, and quality management). After analyzing several articles published addressing each of the construction management challenges, safety management has been identified as the most popular research focus. The increased emphasis on improving construction safety with state-of-the-art technology can be considered a positive development. The growth of BIM-related literature during the past five years suggests that BIM has garnered the interest of construction management researchers who have recognized its significance. The non-adoption of BIM in various projects was attributed to the lack of expertise of the project team and the external organizations. The focus of academia on BIM is a positive sign indicating that the aforementioned challenges may now be addressed.

Published literature demonstrated numerous trends in BIM-based construction management research. Developing automated approaches for cost, schedule, quality, and safety management has been one of the most popular research focuses. As an example, the greatest number of articles addressing BIM-based schedule management was based on automated scheduling. Similarly, articles on automated cost estimation, automated hazard detection models, and automated progress monitoring models were the greatest in number under BIM-based cost management, safety management, and quality management, respectively.

BIM and GIS integration has been a popular research area in the recent past, with multiple projects attempting to improve the interoperability between BIM and GIS. This would enable BIM users to use the building and geospatial data from web-based data providers without any hassles. Besides, facility management systems have been integrated with BIM and GIS to provide a better understanding of facility management. Recent studies are applying the integration of BIM and GIS in the geospatial section because of the rising research interest in smart cities, Internet-of-Things, and urbanization.

There are several cutting-edge technologies that could assist with BIM-based predictive decision-making, such as digital twin technology made up of AR and VR. It can create a bridge between the physical and the digital world. It can accelerate risk assessment and production time, enable businesses to schedule predictive maintenance accurately, and facilitate real-time remote monitoring. Although this research identified automated models as one of the BIM-based approaches, it is important to note that automated and intelligent systems are still lacking in the industry. The systems are flexible to adapt to the estimator's rationale and consider a comprehensive set of parameters that affect the decision-making process. AI could be utilized by researchers to develop robust systems in the construction industry. Data storage and sharing of construction activity among project teams is vital to creating big data analysis methodologies with the aid of BIM.

Although this review has presented some useful BIM-based construction management approaches, a number of knowledge gaps have been identified. The gaps and suggestions for future research in each section are as follows:

Schedule management: At first, given the current gaps related to the reliability of short-term construction planning, further research is required to gain hands-on experience in mobile applications and device specifications needed for the process. Second, recognizing that the vast range of forms and geometrics of plan layouts, multiple beam sections, and various floor levels tend to be severely complex and error-prone. Therefore, an on-site sensor-based twinning approach can enhance project efficiency. Third, to reduce the technical limitations and potential errors arising from manual work and to enhance automation, BIM can be integrated with AI. To improve the level of data consistency among software systems, advanced open file formats should be developed.

Cost Management: Construction costs are associated with numerous uncertainties. Using a comprehensive machine learning model that considers all possible factors, it is possible to improve the accuracy of cost prediction. The database of this model must be developed for all types of buildings, such as residential, commercial, and factories. BIM-based clash detection plays an indispensable role in minimizing construction costs. Future researchers are encouraged to extend the previous research schema by adding new factors, such as varying project sizes and design complexities, to demonstrate BIM capabilities in clash detection. Fast analysis capabilities of different project alternatives are another future avenue studies should focus on to maximize BIM capabilities.

Safety Management: As evidenced by this study, numerous research has dealt with construction workers' health and safety. However, safety management lacks a BIM integrated system to assess the risk of any project. Therefore, a method must be developed to derive construction safety data from a BIM model and assess the risk of construction hazards as well as the total risk of a construction project. The safety of buildings can be considered at the design stage in terms of fire safety and public safety, where regulations are imposed by authorities. BIM-based frameworks seem like an ideal solution for such code-complying activities where the designer is benefited through the prevention of later changes while authorities benefit from efficient communication with designers. This study sheds light upon the above avenues for future scholars seeking to study its practical aspects specifically.

Quality Management: Developing automated systems for monitoring construction processes could be an appropriate subject for future research. This BIM-based system could be integrated with some image recognition and processing methods that are specifically designed to process pixel data. This process would aid with the integration of the industrial Internet-of-Things into the construction industry. The introduction of mobile-based solutions for the QA/QC process is a potential avenue for research in future.

A significant portion of the literature reviewed by the authors demonstrates that both testing and commercial software tools are available for the approaches discussed in this study. However, there seems to be a lag in their utilization and practical application in construction when compared to industries like manufacturing. Apart from selected management sections, BIM implementation must be researched more thoroughly to understand the cost of BIM implementation, Resistance from SMEs, amendments needed in government regulations, and the reduction of complexity of BIM.

In terms of the construction management challenges reviewed in this study, it can be concluded that state-of-the-art technologies and techniques are indispensable to addressing any potential challenges before initiating construction projects. Predictive decision-making helps managers prevent cost and time overruns, identify and assess safety risks, and resolve any existing inaccuracies during the pre-construction stage. Therefore, it is vital for managers to adopt and implement cutting-edge BIM-based methods to optimize construction management.

Appendix

See Tables 2, 3, 4, 5 and Figs. 1, 2.

Table 2 Articles related to BIM-based schedule management

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Schedule Overlap and Delay Minimization	Automated Scheduling	Error and Incompleteness Detection			
(Moon et al., 2015)	✓		✓	The integration of BIM, Fuzzy theory, and Genetic Algorithm (GA) to enhance the operational performance of a project	Korea	2015
(Wang & Song, 2016)	✓	✓		The integration of BIM, Industry Foundation Classes (IFC) file, and GA to provide an optimal schedule	China	2016
(Liu et al., 2015)		✓	✓	The integration of BIM, simulation, optimization, and ontology to facilitate the automatic generation of optimized activity level construction schedule for under resource constraints building projects	Canada	2015
(Song et al., 2012)	✓	✓		The integration of BIM, simulation, optimization, and ontology to manage construction schedules by conducting a dynamic visualization of the construction procedure given the optimized schedules	Korea	2012
(Karan & Irizarry, 2015)	✓	✓		The integration of BIM, GIS, and Semantic Web (SW) technology to process the transferred data between construction project participants	USA	2015
(Karan et al., 2016)	✓	✓		The integration of BIM, GIS, and Semantic Web (SW) technology to process the transferred data between construction project participants	USA	2015
(Kang & Hong, 2015)	✓	✓		The integration of BIM and GIS to improve facilities management	Korea	2015
(Chen et al., 2020)	✓			The integration of BIM with RFID to enable managers to track and match both the dynamic site needs and supply status of materials	China	2020
(Chen & Nguyen, 2019)	✓	✓		The integration of BIM and WMS to present a source selection of sustainable construction materials as a decision support tool	Taiwan	2019
(Malacarne, 2018)		✓		The integration of BIM, Work Breakdown Structure (WBS) to apply construction schedule in the context of small and medium-sized enterprises	Italia	2018
(Mikulakova et al., 2010)		✓		The integration of BIM and Case-based Reasoning (CBR) to solve difficulties in the construction process and determine the planning subject	Germany	2010
(Abbott & Chua, 2020)		✓		The integration of BIM with RFID to improve prefabricated construction scheduling	Singapore	2020
(Ziwei Wang, 2019)		✓		The integration of BIM, Rule-based Reasoning (RBR), and CBR reasoning to generate automated schedules for concrete-framed buildings	Canada	2019

Table 2 (continued)

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Schedule Overlap and Delay Minimization	Automated Scheduling	Error and Incompleteness Detection			
(Moayeri et al., 2017)		✓		The integration of BIM and Application Programming Interface (API) to quantify the ripple effect of owner-requested design changes	Canada	2017
(Bortolini et al., 2019)	✓			The integration of BIM and Last Planner System (LPS) to handle the complexity involved in construction projects	Brazil	2019
(Heigermoser et al., 2019)	✓			The integration of BIM and LPS to enhance productivity and decrease construction waste	Germany	2019
(Konyushkov et al., 2020)	✓			A BIM-based study to digitalize geotechnical works and reduce reworks	Russia	2020
(Cheng & Chang, 2019)		✓		The integration of BIM, optimization, and ontology to investigate the optimization of material layout from the perspective of dynamic task scheduling	Taiwan	2018
(Wang et al., 2018)		✓		The integration of BIM and laser scanner data (LSD) to automatically estimate the dimensions of precast concrete bridge deck panels	Singapore	2018
(Getuli & Capone, 2019)		✓		Ontologies the construction schedule knowledge to develop a BIM-based automatic scheduling system	Italy	2019
(Getuli, 2020)		✓		Ontology-based knowledge modeling in construction planning	Italy	2020
(Abbasi et al., 2021)	✓			The integration of BIM with Takt Time and Discrete Event Simulation (DES) to achieve optimal planning	Iran	2020
(Wu, 2021)	✓	✓		Integrated BIM technology and traditional construction schedule control methods to increase the BIM-related application process without changing the original schedule control process	China	2021

Table 3 Articles related to BIM-based cost management

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Automatic Cost Estimation and Prediction	Cost Optimization	Risk Management			
(Zhiliang et al., 2011)	✓			The integration of IFC standard with BIM to provide a sound foundation for developing the construction cost estimator software	China	2011
(Ma et al., 2013)				The integration of IFC standard with BIM to provide a sound foundation for developing the construction cost estimator software	China	2013
(Shen & Issa, 2010)	✓			Using BIM-Assisted Detailed Estimating (BADE) tools to present a quantified evaluation method	USA	2010
(Cheung et al., 2012)	✓			The integration of New Rule Measurement (NRM) with BIM to evaluate the economics and performance of the buildings, as well as their functionality in the design stage	England	2012
(Sun et al., 2015)			✓	The integration of BIM and earned value analysis (EVA) to develop a cost and schedule risk early warning model	China	2015
(Wang et al., 2016)	✓		✓	The integration of BIM with cost-based progress curve (called S-curve) to combine schedule and cost management for data acquisition and storage	Taiwan	2016
(Huang & Hsieh, 2020)	✓		✓	The integration of BIM with random forest and simple linear regression to predict BIM labor cost	Taiwan	2020
(Vandenbergh & Pyl, 2020)	✓		✓	The integration of BIM with Life Cycle Costing (LCC) to improve the economic dimension of the sustainability concept	Belgium	2020
(Mashayekhi & Heravi, 2020)		✓		The integration of BIM with Management Information Systems (MIS) to optimize cost trade-off and energy consumption of smart building's equipment	Iran	2020
(Lawrence et al., 2014a)	✓		✓	The integration of BIM with Query languages to increase the impact of cost management in the dangerous chemical construction project	USA	2014
(Lee et al., 2020)	✓			The integration of BIM with LCC to predict the cost of the project in the early design phase	Korea	2020
(Kehily & Underwood, 2017)			✓	The integration of BIM with the spreadsheet to recognize barriers that prevent utilizing the life cycle costing process and improve the efficiency of construction projects	Ireland	2017
(Hong et al., 2020)			✓	The integration of BIM with neural network analysis to provide multi-label and multi-class classifications for cost prediction of projects	England	2020
(Lu et al., 2014a, 2014b)			✓	The integration of BIM with Cost–benefit analysis (CBA) to measure BIM benefits for cost estimating	Hong Kong	2014
(Cha & Lee, 2015)		✓		The integration of BIM with time/cost analysis to remodel an aged-housing project	Korea	2015
(Lee et al., 2014)	✓	✓		The integration of BIM with ontology and semantic technology to help engineers to find work items easily	Korea	2013

Table 3 (continued)

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Automatic Cost Estimation and Prediction	Cost Optimization	Risk Management			
(Niknam & Karshenas, 2015)	✓			The integration of BIM with ontology and semantic technology to enable combining, accessing, and sharing information over the internet in a machine-processable format	USA	2015
(Xu et al., 2016)	✓			The integration of BIM with ontology and semantic technology to obtain data from the BIM linked to a project and utilize it to make the essential items for a bill of quantity is established	England	2016
(Faghihi et al., 2016)		✓		The integration of BIM with optimization and Pareto Front analysis as well as GA to develop graphical relationships between pre-defined objectives of schedule optimizations which in turn leads to cost and schedule optimization	USA	2016
(Chahrour et al., 2020)			✓	The integration of BIM with a cost–benefit analysis to evaluate the clash detection ability of BIM for cost savings	Germany	2020
(Eleftheriadis et al., 2018)	✓	✓		The integration of BIM with optimization and GA and FEM to aid managers in early design decisions	England	2018
(Vitiello et al., 2019)		✓	✓	The integration of BIM with optimization to enhance the feasibility of evaluating the economic performance and economic losses of a building exposed to seismic risk and deal with a huge amount of data	Italy	2019
(He et al., 2019)		✓	✓	The integration of BIM with GA and optimization and Pareto Front analysis to deal with the complicated problem of period and cost	China	2019
(Krasny et al., 2017)			✓	The integration of BIM with an energy analysis to prove straw bale houses as healthier and more cost-effective than concrete/brick homes usually built-in Balkan region	Bosnia and Herzegovina	2017
(Ding & Lu, 2021)	✓	✓		Using BIM technology and neural network model, and effectively using the price advantage of ICT, the researchers managed to strictly control the cost	China	2021
(Yang, 2021)		✓		The integration of BIM enhanced the dynamic management of project costs and improve the resource utilization	China	2021
(Yun, 2021)		✓		Developed a framework by adding element and space information that can be linked to the BIM model to the traditional BOQ, which enables the integrated operation of the BIM applied construction cost management system	Korea	2021

Table 4 Articles related to BIM-based safety management

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Collaboration and Communication Enhancement	Hazard Detection	Safety Planning and Scheduling			
(Succar & Kassem, 2015)	✓			Some macro-adoption models such as matrices and a chart are introduced to systematically evaluate BIM adoption across markets and inform the structured progress of country-specific BIM adoption policies	Australia	2015
(Succar, 2009)	✓			The integration of BIM with ontology to introduce a framework to investigate the delivery foundation for industry stakeholders	Australia	2009
(Ciribini et al., 2016)	✓		✓	The integration of BIM and IFC to support the management of pre-construction and construction stages, operating advanced model and code checking, and analysis of the construction stage	Italy	2016
(Dossick et al., 2010)	✓			The use and influence of BIM for mechanical, electrical, plumbing, and fire life safety coordination	USA	2010
(Eadie et al., 2013)	✓			Measurement of BIM impacts on stakeholder collaboration during the lifecycle of construction projects to help the fragmentation reduction in the construction industry	England	2013
(Chen et al., 2020a, 2020b)	✓	✓		The integration of BIM with AR for the maintenance of fire safety equipment	Taiwan	2020
(Golparvar-fard et al., 2011)	✓	✓	✓	The integration of BIM with D4AR to monitor safety and improve collaboration and coordination	USA	2011
(Le & Hsiung, 2014)	✓	✓	✓	The integration of BIM with mobile web map service and GIS to enable useful and essential data exchange in real-time	Vietnam	2014
(Getuli et al., 2020a)			✓	The integration of BIM with Virtual Reality (VR) to improve workspace planning	Italy	2020
(Getuli et al., 2020b)	✓		✓	BIM and VR-based safety implementation protocol	Italy	2020
(Nawari, 2012)	✓			The integration of BIM with IDM to facilitate more reliable information exchange between project participants	USA	2012
(Liu et al., 2020)		✓		The integration of BIM with Indoor positioning system-inertial measurement unit (IPS-IMU) to develop an automated real-time warning system	USA	2020
(Niu et al., 2016)	✓	✓		The introduction on the integration of BIM with Smart Construction Objects (SCOs) to enable a safer, greener, more productive, and efficient construction system	Hong Kong	2016

Table 4 (continued)

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Collaboration and Communication Enhancement	Hazard Detection	Safety Planning and Scheduling			
(Park & Kim, 2013)	✓	✓		The integration of BIM with Augmented Reality (AR), location tracking, and game engine to improve the real-time collaboration between manager and workers, hazard detection, and increase the risk recognition capacity of workers	Korea	2013
(Du et al., 2020)		✓		The integration of BIM with finite element analysis to improve scaffolding safety	China	2020
(Park & Kim, 2015)	✓	✓		Use of open-BIM to automatically check construction safety	Korea	2015
(Nhi & Tran, 2020)			✓	BIM-based research to manage workers' work-space conflicts	Vietnam	2020
(Liu et al., 2019)	✓	✓		The integration of BIM with augmented Unmanned aerial vehicles (UAV) to enhance safety inspection efficiency as well as enable managers to make timely and comprehensive safety decisions	China	2019
(Teo et al., 2017)	✓	✓		The use of BIM to develop a framework for enhancing productivity and safety monitoring systems	Singapore	2017
(Tresidder, 2018)	✓		✓	The use of BIM to apply an off-site manufacturing strategy for accelerating project delivery and improving the level of safety	England	2018
(Qi et al., 2014a, 2014b)		✓		A BIM-based approach for automatically fall hazards checking in building information models then provides design alternative to users	USA	2014
(Zhang et al., 2013)	✓	✓	✓	An automated model to identify hazards and corrections during the design phase with the use of BIM	USA	2012
(Zhang et al., 2015b)		✓		A BIM-based approach to investigate the fall hazards and eliminate them in the early stages of construction projects	USA	2015
(Melzner et al., 2013)	✓	✓	✓	To check the safety hazard in models in the planning process, the applied rule-based checking algorithms are designed to be add-ons to existing BIM software	Germany	2013
(Chavada et al., 2012)		✓	✓	The integration of BIM with CPM to manage the Activity Execution Workspace (AEW) and provide real-time management	England	2014
(Wang et al., 2015a, 2015b)		✓	✓	The integration of BIM with a range point cloud data to detect fall and cave-in hazards linked to excavation pits and models, among other temporary geotechnical excavation objects that are essential fall protection equipment	Germany	2015

Table 4 (continued)

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Collaboration and Communication Enhancement	Hazard Detection	Safety Planning and Scheduling			
(Akula et al., 2013)		✓		The integration of BIM with 3D imaging technology to investigate real-time monitoring approaches for hazardous engineering processes	USA	2013
(Bansal, 2011)		✓	✓	The integration of BIM with GIS to develop a safe execution sequence	India	2011
(Ding et al., 2016)		✓		The integration of BIM with ontology and semantic web technology to provide a framework for the management of risk knowledge in the BIM environment	China	2016
(Forsythe, 2014)		✓		The integration of BIM with a real-time audio warning to help in the recording of data and the ability to make relatively objective observations from them	Australia	2014
(Golovina et al., 2016)		✓		The integration of BIM with GPS to introduce a method for recording, detecting, and analyzing interactive hazardous near-miss situations between workers-on-foot and heavy construction equipment	Germany	2016
(Hu et al., 2008)	✓	✓	✓	A BIM-based framework to automatically generate a resistance model, structural geometry, and loading conditions	China	2008
(Hu et al., 2010a)		✓		The integration of BIM with a developed algorithm using boundary representation (B-rep) method to detect construction collision for site entities to enhance safety management	China	2010
(Hu et al., 2010b)		✓		The use of BIM to present a scaffold safety analysis method during construction	China	2010
(Kim et al., 2015)		✓		The integration of BIM with a project management information system (PMIS) to compose a query set for automatically search for and provide similar accident cases	Korea	2015
(Kim et al., 2016a, 2016b)		✓		The integration of BIM with Real-time locating system (RTLS) to reduce the time laborers are exposed to a hazard	Korea	2016
(Kim & Teizer, 2014)	✓	✓		The use of BIM for scaffolds to combine temporary structures into an approach of checking the safety	Korea	2014
(Li et al., 2015)		✓		The integration of BIM with PBBS that uses simulation and real-time location system to improve safety management	Hong Kong	2015
(Luo & Gong, 2015)		✓		The use of BIM to present code compliance checking for deep foundation construction	China	2015

Table 4 (continued)

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Collaboration and Communication Enhancement	Hazard Detection	Safety Planning and Scheduling			
(Malekitabar et al., 2016)		✓		A BIM-based study to help managers to detect more than 40% of potential fatalities in construction projects by providing five sets of safety risk drivers	Iran	2016
(Riaz et al., 2014)		✓		The integration of BIM with Wireless Sensor Technology (WST) to decrease hazards in the construction site	Pakistan	2014
(Teizer, 2015)	✓	✓	✓	The integration of BIM with unmanned aerial vehicles and laser scanning to sense and track construction assets and workforce automatically to improve safety	Germany	2015
(Wang et al., 2013)		✓	✓	The use of BIM within facilities management to improve safety management related to space planning and energy analysis	China	2013
(Zhang & Hu, 2011)		✓	✓	The integration of BIM with construction simulation and to analyze safety and conflict during construction	China	2011
(Zhang et al., 2015a)		✓	✓	The integration of BIM with ontology to provide automated safety planning for analyzing job hazards	USA	2015
(Zhang et al., 2015c)		✓	✓	The integration of BIM with GPS to resource location tracking and analyze work-space requirements in construction projects	USA	2015
(Bannier & Goodrum, 2016)			✓	The integration of BIM with the knowledge of work envelope requirements to enhance the efficiency of work-space management	USA	2016
(Bansal & Pal, 2014)			✓	The integration of BIM with GIS to improve construction safety by extracting information from the database and linking with respective activities in a schedule developed in GIS	India	2011
(Chen & Luo, 2014)	✓		✓	The use of BIM to develop a model in a product, organization, and process data definition structure	China	2014
(Choi et al., 2014a)			✓	The use of BIM to enhance work-space problem detection and status representation	Korea	2014
(Hartmann et al., 2012)			✓	The introduction of two BIM-based tools to support risk management activities in a construction project	Netherland	2012
(Kim & Teizer, 2014)			✓	The use of BIM to design and plan scaffolding systems automatically	USA	2014
(Marzouk & Abubakr, 2016)			✓	The integration of BIM with GA to ensure the tower crane group safety operation	Egypt	2016

Table 4 (continued)

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Collaboration and Communication Enhancement	Hazard Detection	Safety Planning and Scheduling			
(Moon et al., 2014a)			✓	The integration of BIM with a developed algorithm to detect schedule and work-space conflict	Korea	2014
(Moon et al., 2014b)			✓	The integration of BIM and GA to develop an active simulation system for minimizing the simultaneous interference level of the schedule-work-space	Korea	2014
(Cheung et al., 2018)		✓		The integration of BIM with Wireless Sensor Network (WSN) to monitor safety status via a spatial-colored interface and automatically remove any hazardous gas	Taiwan	2018
(Mihić et al., 2018)		✓		The integration of BIM with specially developed construction hazards database to decrease the number of accidents and injuries by an automated hazard detection	Croatia	2018
(Cheng et al., 2017)		✓		The integration of BIM with evacuation/rescue route optimization with Bluetooth-based technology for preventing building fire and disaster relief	Taiwan	2017
(Ganah & John, 2017)		✓	✓	The use of BIM to improve health and safety on-site management	England	2017
(Kim et al., 2019)		✓	✓	The use of BIM to provide a framework to make safe scaffolding plans without excessive manual effort	USA	2018
(Kim et al., 2018)		✓	✓	The use of BIM to develop a scaffolding plan that considers workflow, cost, and duration and, at the same time, minimizes safety hazards	USA	2018
(Jeewoong Park et al., 2017)		✓	✓	The integration of BIM with Bluetooth Low-Energy (BLE)-based location detection technology and a cloud-based communication platform to improve monitoring system of safety	USA	2017
(Freimuth & König, 2019)			✓	The integration of BIM with UAV to provide an automated acquisition processing of as-built	Germany	2019
(Mirahadi et al., 2019)		✓	✓	The integration of BIM with IFC-centric performance-based evaluation and fire dynamics simulation to improve construction safety	Canada	2019
(Marzouk & Al Daour, 2018)		✓	✓	The integration of BIM with computer simulation to present a method for planning labor evacuation for construction sites	Egypt	2018
(Fan et al., 2021)		✓		Developed a conceptual framework by integrating BIM with internet of things, which enhanced the identification of hazards	China	2021

Table 4 (continued)

Study	BIM-based Approaches			Techniques and Purposes	Country	Year
	Collaboration and Communication Enhancement	Hazard Detection	Safety Planning and Scheduling			
(Liu, 2021)			✓	Mountain rainfall estimation and BIM technology is integrated to enhance site safety management	China	2021
(Akinlolu & Haupt, 2021)			✓	BIM-based visualization technologies are adapted to enhance construction safety management system	South Africa	2021
(Chen et al., 2021)			✓	Enhanced fire safety and safety upskilling through integration of BIM, internet of thing and AR/VR technologies	Australia	2021
(Yu et al., 2021)			✓	The study integrated BIM technology into safety management system, improved the safety management level of construction from the three dimensions of safety, progress, and quality	China	2021

Table 5 Articles related to BIM-based quality management

Study	BIM-based Approach			Techniques	Country	Year
	Lean Construction	Collaboration and Communication Improvement	Automated Progress Monitoring			
(Park et al., 2013)	✓			The integration of BIM with AR and ontology-based data collection template to present construction defect management framework	Korea	2013
(Kwon et al., 2014)	✓			The integration of BIM with image-matching and AR to develop a system to improve reinforced concrete defect management	Korea	2014
(Chen & Luo, 2014)	✓			The use of BIM to develop a model in a product, organization, and process data definition structure	China	2014
(Yan, 2017)	✓			The use of BIM to design prefabricated and assembled concrete structures for improving construction quality management	China	2017
(Kubicki et al., 2019)		✓		The integration of BIM with Smart Whiteboard systems to make synchronous interactive devices for enhancing coordination between participants	Luxembourg	2019
(Chen & Lu, 2019)	✓	✓		To make the mechanism linking BIM and Information Management for improving the information quantity, quality, and accessibility	China	2019
(Lin & Yang, 2018)		✓		The use of BIM collaboration management method to decrease the required time for model checking and enhance work quality	Taiwan	2018
(Deng et al., 2020)			✓	The integration of BIM with computer vision to develop an automated progress monitoring of tiles	China	2020

Table 5 (continued)

Study	BIM-based Approach			Techniques	Country	Year
	Lean Construction	Collaboration and Communication Improvement	Automated Progress Monitoring			
(Wang et al., 2018)			✓	The integration of BIM and LSD to automatically estimate the dimensions of precast concrete bridge deck panels for improving quality inspection of panels	Singapore	2018
(Wu et al., 2018)		✓		The integration of BIM with Data Envelopment Analysis (DEA) to enhance the performance of construction by optimum resource allocation	China	2018
(Ma et al., 2018)		✓	✓	The integration of BIM with indoor positioning technology to make effective and collaborative quality management	China	2018
(Lin et al., 2017)	✓			The integration of BIM with Trapezoid Structural Transfer Layer to optimize construction procedure and enhance quality control of projects	China	2017
(Lin et al., 2020)			✓	The integration of BIM with Wireless Sensor Network (WSN) to develop a monitoring system for parking garages	Taiwan	2020
(Lin et al., 2016)	✓		✓	The integration of BIM with web-based technology to manage the status and results of the corrective works performed effectively	Taiwan	2016
(Costin et al., 2015)			✓	The integration of BIM with RFID to track workers' location	USA	2015
(Choi et al., 2014b)			✓	The integration of BIM with path analysis to enhance the work-space planning process	Korea	2014
(Jiang et al., 2013)	✓	✓		The integration of BIM with IFC to enhance the productivity of the construction domain and improve text information management	China	2013
(Pour et al., 2020)	✓		✓	The integration of BIM with image processing, machine learning, and VR to improve the quality of progress monitoring in construction projects	England	2020
(Lin, 2015)		✓	✓	The integration of BIM with information systems to improve interface management for rework minimization	Taiwan	2015
(Oh et al., 2015)		✓		An integrated BIM-based system to make a collaborative design for improving the quality and productivity of construction projects	Korea	2015
(Lisha et al., 2018)	✓			The integration of BIM with performance simulation analysis to make up traditional design methods defects and make their design more intuitive	China	2018
(Hamledari et al., 2018)	✓		✓	The integration of BIM with IFC to make inspected building elements auto-updateable on-site observations for enabling potential diagnostics and tractability	USA	2018
(Wang et al., 2015a, 2015b)	✓		✓	The integration of BIM with the point cloud process to extract building geometrics for demystifying and accelerating the as-is building model	USA	2015

Table 5 (continued)

Study	BIM-based Approach			Techniques	Country	Year
	Lean Construction	Collaboration and Communication Improvement	Automated Progress Monitoring			
(Koseoglu et al., 2018)		✓		The use of BIM integrated with lean construction principles in mobile devices to enlighten construction participants concerning site BIM application capabilities	Turkey	2018
(Bosche et al., 2009)			✓	The integration of BIM with laser scanning to present automated object recognition to improve the quality of project monitoring	Canada	2009
(Haoxiong, 2020)			✓	The integration of BIM with 3D laser scanning for improving on-site data acquisition to reach enhanced progress monitoring	China	2020
(Bosché, 2010)			✓	The integration of BIM with laser scanning to automatically recognize 3D CAD model objects as well as calculate as-built dimensions for improving quality control	Switzerland	2010
(Elbeltagi & Dawood, 2011)	✓		✓	The integration of BIM with GIS to help decision-making regarding repetitive construction projects	Egypt	2011
(Turkan et al., 2012)			✓	The integration of BIM with laser scanning to develop an automated progress tracking	Canada	2012
(Irizarry et al., 2013)			✓	The integration of BIM with GIS to monitor the supply chain status and present warning signals to assure the delivery of materials	USA	2013
(Bosché et al., 2014)			✓	The integration of BIM with laser scanning to develop structural works tracking, in particular, MEP works	Canada	2014
(Dimitrov & Golparvar-fard, 2014)			✓	The integration of BIM with support vector machines to classify materials from single images taken under an unknown viewpoint	USA	2014
(Shahi et al., 2015)			✓	The integration of BIM with imaging and Ultra-Wide Band (UWB) to tracking the progress of construction activity	Canada	2015
(Golparvar-fard et al., 2015)		✓	✓	The integration of BIM with IFC to recognize physical progress based on two emerging information sources	USA	2015
(Han & Golparvar-fard, 2015)	✓		✓	The integration of BIM with 3D Point Cloud Models(3PCM) to monitor project progress deviations during construction based on a new appearance-based material categorization approach	USA	2015
(Deng et al., 2019a, 2019b)	✓		✓	The integration of BIM with computer vision to automatically monitor the progress of tiles	China	2019
(Braun & Borrmann, 2019)			✓	The integration of BIM with inverse photogrammetry to label construction site images automatically	Germany	2019
(Mejlænder-larsen, 2018)		✓	✓	The use of BIM to present a process with three steps for minimizing manual reporting and improving its quality	Norway	2018
(Asadi et al., 2019)		✓	✓	The integration of BIM with augmented monocular simultaneous localization and mapping to register video sequence to an as-planned model in real-time	USA	2019

Table 5 (continued)

Study	BIM-based Approach			Techniques	Country	Year
	Lean Construction	Collaboration and Communication Improvement	Automated Progress Monitoring			
(Kropp et al., 2018)		✓	✓	The integration of BIM with computer vision to enhance the automated monitoring of indoor progress	Germany	2018
(Jaehyun Park et al., 2017)		✓	✓	The integration of BIM with web-based methods to make real-time information sharing of daily 4D BIM through enhancing collaboration and communications among project participants	USA	2017
(Rebolj et al., 2017)			✓	The use of the Scan-vs-BIM method to measure the point cloud quality for monitoring the construction procedure	Slovenia	2017
(Bansal & Pal, 2009)	✓			The integration of BIM, and GIS to manage each stage of projects, which in turn causes an impeccable schedule	India	2009
(Park et al., 2018)	✓			The integration of BIM and Content-Based Image Retrieval (CBIR) to automatically register daily photos and determine BIM objects	USA	2018
(Irizarry & Karan, 2012)	✓			The integration of BIM and GIS to identify feasible locations of tower cranes	USA	2012
(Li et al, 2017)	✓			The integration of BIM and RFID to address delay problems in prefabrication housing construction	Hong Kong	2017
(Chen & Tang, 2019)	✓			The integration of BIM and API to propose an innovative management workflow design to implement an efficient schedule of building fabric maintenance	China	2019
(Biagini et al., 2016)	✓			The integration of BIM and LSD to develop an innovative approach regarding restoration of historical building management	Italy	2016
(Kim et al., 2017)	✓			The integration of BIM and direct as well as an indirect method of construction waste quantification to reach efficient and streamlined planning and management	Korea	2017
(Sheikhkhoshkar et al., 2019)	✓			The integration of BIM, Optimization, and Ontology to introduce an automated solution for concrete joint positioning	Iran	2019
(Liu & Hu, 2016)	✓			Applying a 5D model to use in the electric power construction industry to manage and reduce project costs	China	2016
(Shan et al., 2018)	✓			Increasing the impact of cost management in the dangerous chemical construction project by a BIM model	China	2018
(Chahrour et al., 2020)	✓			The integration of BIM with a cost–benefit analysis to evaluate the clash detection ability of BIM for cost savings	Germany	2020
(Nguyen et al., 2021)			✓	BIM model was integrated with 3D laser scanning to replace the manual quality assurance by humans, limiting the inconsistencies in the quality assurance process	Vietnam	2021
(Ma et al., 2021)			✓	The study developed a BIM-based automatic quality inspection framework based on the photographs used	China	2021

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Declarations

Conflict of interest The authors declare no competing interests.

References

Abbasi, S., Taghizade, K., Noorzai, E., & Asce, M. (2021). BIM-based combination of Takt time and discrete event simulation for implementing just in time in construction scheduling under constraints. *Journal of Construction Engineering and Management*. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001940

Abbott, E.L.S., Chua, D.K.H. (2020). The Intelligent use of RFID in Prefabricated, Construction Work Flow and BIM Volumetric, in: MATEC Web of Conferences.

Adriaanse, A., Voordijk, H., & Dewulf, G. (2010). Adoption and Use of Interorganizational ICT in a Construction Project Adoption and Use of Interorganizational ICT. *Journal of Construction Engineering and Management*. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000201

Ahuja, V., Yang, J., & Shankar, R. (2010). Benchmarking framework to measure extent of ICT adoption for building project management. *Journal of Construction Engineering and Management*. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000155

Akinlolu, M., & Haupt, T. C. (2021). Effectiveness of BIM-based visualization technologies for construction site health and safety management: A Meta-synthesis Approach. *IOP Conference Series: Materials Science and Engineering, 1107*, 012176. https://doi.org/10.1088/1757-899X/1107/1/012176

Akula, M., Lipman, R. R., Franaszek, M., Saidi, K. S., Cheok, G. S., & Kamat, V. R. (2013). Real-time drill monitoring and control using building information models augmented with 3D imaging data. *Automation in Construction, 36*, 1–15. https://doi.org/10.1016/j.autcon.2013.08.010

Amir, B., Fernanda, L., K, C.Y., Chao, W. (2019). Automated Mining of Construction Schedules for Easy and Quick Assembly of 4D BIM Simulations. In: Omputing in Civil Engineering 2019 - Visualization, Information Modeling, and Simulation. ASCE, Atlanta, Georgia.

Andradóttir, S., Healy, K.J., Withers, D.H., Nelson, B.L., Sims, M.J. (1997). Proceedings of the 1997 Winter Simulation Conference, in: Simulation Conference. pp. 67–69.

Ansah, M. K., Chen, X., Yang, H., Lu, L., & Lam, P. T. I. (2019). A review and outlook for integrated BIM application in green building assessment. *Sustainable Cities and Society, 48*, 101576. https://doi.org/10.1016/j.scs.2019.101576

Aredah, A., Baraka, M., & Elikhafif, M. (2019). Project scheduling techniques within a building information modeling (BIM) environment: A survey study. *IEEE Engineering Management Review, 47*, 133–143. https://doi.org/10.1109/EMR.2019.2916365

Asadi, K., & M, S., Ramshankar, H., Noghabaei, M., M, S., Han, K., A M,. (2019). Real-time image localization and registration with BIM using perspective alignment for indoor monitoring of construction. *Journal of Computing in Civil Engineering, 33*, 1–15. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000847

Awwad, R., El Souki, O., & Jabbour, M. (2016). Construction safety practices and challenges in a Middle Eastern developing country. *Safety Science, 83*, 1–11. https://doi.org/10.1016/j.ssci.2015.10.016

Ayman, R., Alwan, Z., & McIntyre, L. (2020). BIM for sustainable project delivery: Review paper and future development areas. *Architectural Science Review, 63*, 15–33. https://doi.org/10.1080/00038628.2019.1669525

Azhar, A., Hein, M., Sketo, B., 2008. Building Information Modeling (BIM): Benefits, Risks and Challenges. Proc., 44th Associated Schools of Construction National Conference, Auburn, AL.

Baloi, D., & Price, A. D. F. (2003). Modelling global risk factors affecting construction cost performance. *International Journal of Project Management, 21*, 261–269. https://doi.org/10.1016/S0263-7863(02)00017-0

Bannier, P.J., Goodrum, P.M. (2016). Modeling of work envelope requirements in the piping and steel trades and the influence of global anthropomorphic characteristics. Journal of Information Technology in Construction.

Bansal, V. K. (2011). Application of geographic information systems in construction safety planning. *International Journal of Project Management, 29*, 66–77. https://doi.org/10.1016/j.ijproman.2010.01.007

Bansal, V. K., & Pal, M. (2014). Construction Projects Scheduling Using GIS Tools. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2011.10773158

Bansal, V. K., & Pal, M. (2009). Construction schedule review in GIS with a navigable 3D animation of project activities. *International Journal of Project Management, 27*, 532–542. https://doi.org/10.1016/j.ijproman.2008.07.004

Bansal, V. K., Pal, M., & Modeling, C. A. D. (2008). Generating, evaluating, and visualizing construction. *Journal of Computing in Civil Engineering, 22*, 233–242. https://doi.org/10.1061/(ASCE)0887-3801(2008)22

Behzadan, A.H., Menassa, C.C., Tishman, J.L., Scholar, F., Pradhan, A.R. (2015). Enabling real time simulation of architecture, engineering, construction, and facility management (AEC/FM) systems: a review of formalism, model architecture, and data representation 20, 1–23.

Benjaoran, V. (2009). A cost control system development: A collaborative approach for small and medium-sized contractors. *International Journal of Project Management, 27*, 270–277.

Biagini, C., Capone, P., Donato, V., & Facchini, N. (2016). Automation in construction towards the BIM implementation for historical building restoration sites. *Automation in Construction*. https://doi.org/10.1016/j.autcon.2016.03.003

Blazquez, M.B. (2014). RETAIL Fashion Consumers' Shopping Experiences in the UK and Spain Compared.

Bortolini, R., Torres, C., & Viana, D. D. (2019). Automation in Construction Site logistics planning and control for engineer-to-order prefabricated building systems using BIM 4D modeling. *Automation in Construction, 98*, 248–264. https://doi.org/10.1016/j.autcon.2018.11.031

Bosché, F. (2010). Automated recognition of 3D CAD model objects in laser scans and calculation of as-built dimensions for dimensional compliance control in construction. *Advanced Engineering Informatics, 24*, 107–118. https://doi.org/10.1016/j.aei.2009.08.006

Bosché, F., Guillemet, A., Turkan, Y., Asce, A. M., Haas, C. T., Asce, F., Haas, R., & Asce, F. (2014). Tracking the Built Status of MEP Works: Assessing the Value of a Scan-vs. -BIM System. *Journal of Computing in Civil Engineering, 28*, 1–13. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000343

Bosche, F., & M, Haas, C.T., M, Akinci, B., M,. (2009). Automated recognition of 3D CAD objects in site laser scans for project 3D status visualization and performance control. *Journal of Computing in Civil Engineering, 23*, 311–318. https://doi.org/10.1061/(ASCE)0887-3801(2009)23

Braun, A., & Borrmann, A. (2019). Combining inverse photogrammetry and BIM for automated labeling of construction site images for machine learning. *Automation in Construction*. https://doi.org/10.1016/j.autcon.2019.102879

Braun, A., Tuttas, S., Borrmann, A., & Stilla, U. (2015). A concept for automated construction progress monitoring using BIM-based geometric constraints and photogrammetric point clouds. *Journal of Information Technology in Construction, 20*, 68–79.

Bryant, M.F. (2009a). A comparison of the rule and case-based reasoning approaches for the automation of help-desk operations at the tier-two level. Nova Southeastern University.

Bryant, M.F. (2009b). A comparison of the rule and case-based reasoning approaches for the automation of help-desk operations at the tier-two level. Nova Southeastern University.

Cha, H. S., & Lee, D. G. (2015). A case study of time / cost analysis for aged-housing renovation using a pre-made BIM database structure. *KSCE Journal of Civil Engineering, 19*, 841–852. https://doi.org/10.1007/s12205-013-0617-1

Chahrour, R., Hafeez, M. A., Ahmad, A. M., Sulieman, I., Dawood, H., Rodriguez-trejo, S., Naji, K. K., & Dawood, N. (2020). Cost-benefit analysis of BIM-enabled design clash detection and resolution. *Construction Management and Economics*. https://doi.org/10.1080/01446193.2020.1802768

Chang, Y.T., Hsieh, S.H. (2020). A review of building information modeling research for green building design through building performance analysis. Journal of Information Technology in Construction 25, 1–40. https://doi.org/10.36680/j.itcon.2020.001

Chassiakos, A. P., & Sakellaropoulos, S. P. (2008). *Advances in Engineering Software A Web-Based System for Managing Construction Information, 39*, 865–876. https://doi.org/10.1016/j.advengsoft.2008.05.006

Chen, C., & Tang, L. (2019). BIM-based integrated management work fl ow design for schedule and cost planning of building fabric maintenance. *Automation in Construction, 107*, 102944. https://doi.org/10.1016/j.autcon.2019.102944

Chen, H., Hou, L., Zhang, G., & (Kevin), Moon, S.,. (2021). Development of BIM, IoT and AR/VR technologies for fire safety and upskilling. *Automation in Construction, 125*, 103631. https://doi.org/10.1016/j.autcon.2021.103631

Chen, K., & Lu, W. (2019). Bridging BIM and building (BBB) for information management in construction implementation. *Engineering, Construction and Architectural Management, 26*, 1518–1532. https://doi.org/10.1108/ECAM-05-2018-0206

Chen, L., & Luo, H. (2014). A BIM-based construction quality management model and its applications. *Automation in Construction, 46*, 64–73. https://doi.org/10.1016/j.autcon.2014.05.009

Chen, P., & Nguyen, T. C. (2019). Automation in Construction A BIM-WMS integrated decision support tool for supply chain management in construction. *Automation in Construction, 98*, 289–301. https://doi.org/10.1016/j.autcon.2018.11.019

Chen, Y., Lai, Y., & Lin, Y. (2020a). BIM-based augmented reality inspection and maintenance of fi re safety equipment. *Automation in Construction, 110*, 103041. https://doi.org/10.1016/j.autcon.2019.103041

Chen, Q., Adey, B. T., Haas, C., & Hall, D. M. (2020b). Using look-ahead plans to improve material flow processes on construction projects when using BIM and RFID technologies. *Construction Innovation, 20*, 471–508. https://doi.org/10.1108/CI-11-2019-0133

Cheng, M., Chiu, K., Hsieh, Y., Yang, I., Chou, J., & Wu, Y. (2017). BIM integrated smart monitoring technique for building fi re prevention and disaster relief. *Automation in Construction, 84*, 14–30. https://doi.org/10.1016/j.autcon.2017.08.027

Cheng, M. Y., & Chang, N. W. (2019). Dynamic construction material layout planning optimization model by integrating 4D BIM. *Engineering with Computers, 35*, 703–720. https://doi.org/10.1007/s00366-018-0628-0

Cherneff, J., Logcher, R., & Sriram, D. (1991). Integrating CAD with construction schedule generation. *Journal of Computing in Civil Engineering*. https://doi.org/10.1061/(ASCE)0887-3801(1991)5:1(64)

Cheung, F. K. T., Rihan, J., Tah, J., Duce, D., & Kurul, E. (2012). Early stage multi-level cost estimation for schematic BIM models. *Automation in Construction, 27*, 67–77. https://doi.org/10.1016/j.autcon.2012.05.008

Cheung, W., Lin, T., & Lin, Y. (2018). a real-time construction safety monitoring system network and building information modeling technologies. *MDPI*. https://doi.org/10.3390/s18020436

Chin, S., Kim, K., & Kim, Y. (2004). A process-based quality management information system. *Automation in Construction, 13*, 241–259. https://doi.org/10.1016/j.autcon.2003.08.010

Choi, B., Lee, H., Asce, A. M., Park, M., Asce, A. M., Cho, Y. K., Asce, A. M., Kim, H., & Asce, S. M. (2014a). Framework for work-space planning using four-dimensional BIM in construction projects. *Journal of Construction Engineering and Management, 140*, 1–13. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000885

Choi, B., Lee, H., & M, A., Park, M., M, A., Cho, Y.K., Asce, A.M., Kim, H., M, S.,. (2014b). Framework for work-space planning using four-dimensional BIM in construction projects. *Journal of Construction Engineering and Management, 140*, 1–13. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000885

Chou, J. (2011). Cost simulation in an item-based project involving construction engineering and management. *JPMA, 29*, 706–717. https://doi.org/10.1016/j.ijproman.2010.07.010

Ciribini, A. L. C., Ventura, S. M., & 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, 71*, 62–73. https://doi.org/10.1016/j.autcon.2016.03.005

Construction Industry Institute (2003). Benchmarking and Metrics Value of Best Practices Report. The Univ. of Texas at Austin, Austin, Tex., 1–48.

Cooke, A. J. (1996). *The economic evaluation of construction projects*. Springer.

Costin, A.M., Teizer, J., Schoner, B., Thingmagic, T. (2015). RFID and bim-enabled worker location tracking to support real-time building protocol control and data visualization. - Journal of Information Technology in Construction 20, 495–517.

Crotty, R. (2012). *The impact of building information modeling*. Spoon Press.

Curry, E., O'Donnell, J., Corry, E., Hasan, S., Keane, M., & O'Riain, S. (2013). Linking building data in the cloud: Integrating cross-domain building data using linked data. *Adv. Eng. Inf., 27*(2), 206–219.

Cusack, D., 1992. Implementation of ISO 9000 in Construction. ISO 9000 Forum Symp,.

Davidson, A., & Gales, J. (2021). High-rise buildings BIM and fire safety engineering-overview of state of the art. *International Journal of High-Rise, 10*, 251–263.

Davis, F., Devine, M., & Lutz, R. (1974). Scheduling activities among conflicting facilities to minimize conflict cost. *Mathematical Programming, 6*, 224–228.

DBIS. (2013). *UK Construction: An economic analysis of the sector*. Department for Business, Innovation and Skills.

Dehghan, R., & Ruwanpura, J. Y. (2011). The mechanism of design activity overlapping in construction projects and the time-cost tradeoff function. *Procedia Engineering, 14*, 1959–1965.

Demirkan, H. (2015). Innovations with Smart Service Systems: Analytics , Big Data , Cognitive Assistance , and the Internet of Everything Innovations with Smart Service Systems : Analytics , Big Data , Cognitive 37. https://doi.org/10.17705/1CAIS.03735

Deng, H., Hong, H., Luo, D., Deng, Y., Asce, A. M., & Su, C. (2020). Automatic Indoor Construction Process Monitoring for Tiles Based on BIM and Computer Vision. *Journal of Construction Engineering and Management, 146*, 1–12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001744

Deng, H., Hong, H., Luo, D., Deng, Y., Asce, A. M., & Su, C. (2019a). Automatic Indoor Construction Process Monitoring for Tiles Based on BIM and Computer Vision. *Journal of Construction Engineering and Management, 146*, 1–12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001744

Deng, Y., Gan, V. J. L., Das, M., Cheng, J. C. P., & Anumba, C. (2019b). Integrating 4D BIM and GIS for Construction Supply Chain Management. *Journal of Construction Engineering and Management, 145*, 04019016. https://doi.org/10.1061/(asce)co.1943-7862.0001633

Dimitrov, A., & Golparvar-fard, M. (2014). Vision-based material recognition for automated monitoring of construction progress and generating building information modeling from unordered site image collections. *Advanced Engineering Informatics, 28*, 37–49. https://doi.org/10.1016/j.aei.2013.11.002

Ding, L. Y., Zhong, B. T., Wu, S., & Luo, H. B. (2016). *Construction Risk Knowledge Management in BIM Using Ontology and Semantic Web Technology, 87*, 202–213. https://doi.org/10.1016/j.ssci.2016.04.008

Ding, X., & Lu, Q. (2021). Construction cost management strategy based on BIM technology and neural network model. *Journal of Intelligent & Fuzzy Systems, 40*, 6669–6681. https://doi.org/10.3233/JIFS-189502

Dodanwala, T., Shrestha, P., & Santoso, D. S. (2021). Role conflict related job stress among construction project professionals: The moderating role of age and organization tenure. *Construction Economics and Building, 21*, 21–37. https://doi.org/10.5130/AJCEB.v21i4.7609

Dodanwala, T. C., & Santoso, D. S. (2022). The mediating role of job stress on the relationship between job satisfaction facets and turnover intention of the construction professionals. *Engineering, Construction and Architectural Management, 29*, 1777–1796. https://doi.org/10.1108/ECAM-12-2020-1048

Dodanwala, T. C., & Shrestha, P. (2021). Work–family conflict and job satisfaction among construction professionals: The mediating role of emotional exhaustion. *On the Horizon, 29*, 62–75. https://doi.org/10.1108/OTH-11-2020-0042

Dodanwala, T. C., Santoso, D. S., & Shrestha, P. (2022a). The mediating role of work–family conflict on role overload and job stress linkage. *Built Environment Project and Asset Management*. https://doi.org/10.1108/BEPAM-12-2021-0153

Dodanwala, T.C., Santoso, D.S., Yukongdi, V. (2022b). Examining work role stressors, job satisfaction, job stress, and turnover intention of Sri Lanka's construction industry. https://doi.org/10.1080/15623599.2022.2080931

Doloi, H. (2013). Cost Overruns and Failure in Project Management: Understanding the Roles of Key Stakeholders in Construction Projects. *Journal of Construction Engineering and Management*. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000621

Donato, V., Lo Turco, M., & Bocconcino, M. M. (2018). BIM-QA/QC in the architectural design process. *Architectural Engineering and Design Management, 14*, 239–254. https://doi.org/10.1080/17452007.2017.1370995

Dossick, C. S., Asce, M., & Neff, G. (2010). *Organizational Divisions in BIM-Enabled Commercial Construction, 136*, 459–467. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000109

Du, C., Bing, B., Mao, X., Liu, W., Liu, Y., Xu, Q. (2020). Research on Automatic Monitoring and Early Warning System Based on BIM Smart Infrastructure Risk, in 6th International Conference on Environmental Science and Civil Engineering.

Dziadosz, A., & Konczak, A. (2016). Review of selected methods of supporting decision-making process in the construction industry.". *Archives of Civil Engineering, 62*, 111–126.

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

Eastman, C. (1999). *Building product models: Computer environments*. CRC Press, Boca Raton, FL.

Eastman, C., Teicholz, P., & S.R. and L.K.,. (2011). *BIM handbook: A guide to building information modeling for owner, managers, designers, engineers, and contractors* (2nd ed.). Wiley., Appl. Phys. A.

Elbeltagi, E., & Dawood, M. (2011). Integrated visualized time control system for repetitive construction projects. *Automation in Construction, 20*, 940–953. https://doi.org/10.1016/j.autcon.2011.03.012

Eleftheriadis, S., Duffour, P., Greening, P., James, J., Stephenson, B., & Mumovic, D. (2018). Energy & buildings investigating relationships between cost and CO2 emissions in reinforced concrete structures using a BIM-based design optimisation approach. *Energy & Buildings, 166*, 330–346. https://doi.org/10.1016/j.enbuild.2018.01.059

Elwakil, E., Zayed, T., 2012. Data Management for Construction Processes Using Fuzzy Approach. In Construction Research Congress, West Lafayette, Indiana. ASCE, 778–786. https://doi.org/10.1061/9780784412329.123

Faghihi, S. V., Nejat, A., Reinschmidt, K., & Kang, J. H. (2015). Automation in construction scheduling: A review of the literature. *The International Journal of Advanced Manufacturing Technology, 81*, 1845–1856. https://doi.org/10.1007/s00170-015-7339-0

Faghihi, V., Reinschmidt, K. F., & Kang, J. H. (2016). Objective-driven and Pareto front analysis: Optimizing time, cost, and job-site movements. *Automation in Construction, 69*, 79–88. https://doi.org/10.1016/j.autcon.2016.06.003

Fan, W., Zhou, J., Zhou, J., Liu, D., Shen, W., & Gao, J. (2021). Safety management system prototype/framework of deep foundation pit based on BIM and IoT. *Advances in Civil Engineering, 2021*, 1–19. https://doi.org/10.1155/2021/5539796

Forcada, N., Casals, M., Roca, X., & Gangolells, M. (2007). *Adoption of Web Databases for Document Management in SMEs of the Construction Sector in Spain, 16*, 411–424. https://doi.org/10.1016/j.autcon.2006.07.011

Forsythe, P., 2014. Proactive construction safety systems and the human factor 167.

Freimuth, H., & König, M. (2019). A Framework for Automated Acquisition and. *MDPI*. https://doi.org/10.3390/s19204513

Fu, C., Aouad, G., & A., L., Wu, S.,. (2006). IFC model viewer to support nD model application. *Automation in Construction, 15*, 178–185. https://doi.org/10.1016/j.autcon.2005.04.002

Ganah, A., & John, G. A. (2015). Integrating Building Information Modeling and Health and Safety for Onsite Construction. *Safety and Health at Work, 6*, 39–45. https://doi.org/10.1016/j.shaw.2014.10.002

Ganah, A. A., & John, G. A. (2017). BIM and project planning integration for on-site safety induction. *Journal of Engineering,* *Design and Technology, 15*, 341–354. https://doi.org/10.1108/JEDT-02-2016-0012

Getuli, V. (2020). Ontologies for Knowledge modeling in construction planning, Firenze University Press, Firenze, Italy. https://doi.org/10.36253/978-88-5518-184-6

Getuli, V., Capone, P. (2019). Ontology-based modeling for construction site planning: Towards an ifcOWL semantic enrichment. 36th International Conference of CIB W78, 701–713.

Getuli, V., Capone, P., Bruttini, A., & Isaac, S. (2020a). BIM-based immersive virtual reality for construction workspace planning: A safety-oriented approach. *Automation in Construction*. https://doi.org/10.1016/j.autcon.2020.103160

Getuli, V., Capone, P., & Bruttini, A. (2020b). Planning, management and administration of HS contents with BIM and VR in construction: An implementation protocol. *Engineering, Construction and Architectural Management, 28*, 603–623. https://doi.org/10.1108/ECAM-11-2019-0647

Golovina, O., Teizer, J., & Pradhananga, N. (2016). Heat map generation for predictive safety planning: Preventing struck-by and near miss interactions between workers-on-foot and construction equipment. *Automation in Construction, 71*, 99–115. https://doi.org/10.1016/j.autcon.2016.03.008

Golparvar-fard, M., Asce, A. M., & Pe, F. (2015). Automated Progress Monitoring Using Unordered Daily Construction Photographs and IFC-Based Building Information Models. *Journal of Computing in Civil Engineering, 29*, 1–19. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000205

Golparvar-fard, M., Asce, M., Peña-mora, F., Asce, M., 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 137, 1099–1116. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000371

Hamledari, H., & M, S., Azar, E.R., M, A., Mccabe, B., A M,. (2018). IFC-Based Development of As-Built and As-Is BIMs Using Construction and Facility Inspection Data : Site-to-BIM Data Transfer Automation. *Journal of Computing in Civil Engineering, 32*, 1–15. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000727

Han, K. K., & Golparvar-fard, M. (2015). Appearance-based material classi fi cation for monitoring of operation-level construction progress using 4D BIM and site photologs. *Automation in Construction, 53*, 44–57. https://doi.org/10.1016/j.autcon.2015.02.007

Han, S., Lee, S., & Peña-Mora, F. (2014). Comparative study of motion features for similarity-based modeling and classification of unsafe actions in construction. *Journal of Computing in Civil Engineering, 28*, 1–11. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000339

Haoxiong, S. M. A. (2020). Three-dimensional laser combined with BIM technology for building modeling, information data acquisition. *Nonlinear Optics, Quantum Optics, 52*, 191–203.

Hardin, B. (2009). *BIM and construction management*. Wiley Publishing, IN.

Hartmann, T., Meerveld, H. V., Vossebeld, N., & Adriaanse, A. (2012). Aligning building information model tools and construction management methods. *Automation in Construction, 22*, 605–613. https://doi.org/10.1016/j.autcon.2011.12.011

He, W., Shi, Y., & Kong, D. (2019). Construction of a 5D duration and cost optimisation model based on genetic algorithm and BIM. *Journal of Engineering, Design and Technology, 17*, 929–942. https://doi.org/10.1108/JEDT-12-2018-0214

Heigermoser, D., García, B., Soto, D., Leslie, E., Abbott, S., Kim, D., Chua, H., Gmbh, H. E., & Main, F. (2019). Automation in construction BIM-based last planner system tool for improving construction project management. *Automation in Construction, 104*, 246–254. https://doi.org/10.1016/j.autcon.2019.03.019

Hong, Y., Hammad, A. W. A., Akbarnezhad, A., & Arashpour, M. (2020). Automation in construction A neural network approach to predicting the net costs associated with BIM adoption. *Automation in Construction, 119*, 103306. https://doi.org/10.1016/j.autcon.2020.103306

Hu, Z., Zhang, J., & Zhang, X. (2010a). Construction collision detection for site entities based on 4-D space-time model. *Engineering Mechanics, 50*, 820–825.

Hu, Z., Zhang, J., & Zhang, X. (2010b). 4D construction safety information model-based safety analysis approach for scaffold system during construction. *Engineering Mechanics, 27*, 192–200.

Hu, Z., Zhan, J., & Deng, Z. (2008). Construction process simulation and safety analysis based on building information model and 4D technology. *Tsinghua Science and Technology, 13*, 266–272.

Huang, C., & Hsieh, S. (2020). Predicting BIM labor cost with random forest and simple linear regression. *Automation in Construction, 118*, 103280. https://doi.org/10.1016/j.autcon.2020.103280

Huang, X. (2021). Application of BIM big data in construction engineering cost. *Journal of Physics: Conference Series, 1865*, 032016. https://doi.org/10.1088/1742-6596/1865/3/032016

Irizarry, J., & Karan, E. P. (2012). Optimizing location of tower cranes on construction sites through GIS and BIM integration. *Electronic Journal of Information Technology in Construction, 17*, 361–366.

Irizarry, J., Karan, E. P., & Jalaei, F. (2013). Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Automation in Construction, 31*, 241–254. https://doi.org/10.1016/j.autcon.2012.12.005

Ismail, A.S. (2017). A Review on BIM-based automated code compliance checking system, in: International Conference on Research and Innovation in Information Systems. IEEE, pp. 1–6.

Iyer, K. C., & Jha, K. N. (2005). *PROJECT Factors Affecting Cost Performance: Evidence from Indian Construction Projects, 23*, 283–295. https://doi.org/10.1016/j.ijproman.2004.10.003

Jato-espino, D., Castillo-lopez, E., Rodriguez-hernandez, J., & Canteras-jordana, J. C. (2014). A review of application of multi-criteria decision making methods in construction. *Automation in Construction, 45*, 151–162. https://doi.org/10.1016/j.autcon.2014.05.013

Ji, S., Park, M., Asce, M., Lee, H., Asce, M., Ahn, J., Kim, N., & Son, B. (2011a). *Military Facility Cost Estimation System Using Case-Based Reasoning in Korea, 25*, 218–231. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000082

Ji, S., Park, M., & Lee, H. (2011b). *Cost Estimation Model for Building Projects Using Case-Based Reasoning, 581*, 570–581. https://doi.org/10.1139/L11-016

Jiang, S., Zhang, H., & Zhang, J. (2013). Research on BIM-based construction domain text information management. *Journal of Networks, 8*, 1455–1465. https://doi.org/10.4304/jnw.8.6.1455-1464

Joshi, V.S.D. (2010). Application of Decision Tree Technique to Analyze Construction Project Data, in: International Conference on Information Systems, Technology and Management. pp. 304–313.

Kang, T. W., & Hong, C. H. (2015). A study on software architecture for effective BIM/GIS-based facility management data integration. *Automation in Construction, 54*, 25–38. https://doi.org/10.1016/j.autcon.2015.03.019

Karan, E. P., & Irizarry, J. (2015). Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services. *Automation in Construction, 53*, 1–12. https://doi.org/10.1016/j.autcon.2015.02.012

Karan, E. P., Irizarry, J., & Haymaker, J. (2016). BIM and GIS integration and interoperability based on semantic web technology.

Journal of Computing in Civil Engineering, 30, 1–11. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000519

Kehily, D., Underwood, J. (2017). Embedding life cycle costing in 5D BIM. Journal of Information Technology in Construction 22.

Khademi, S.S. (2014). Time Overrun Analysis in North Cyprus Building Construction Projects.

Kim, H., Lee, H., Park, M., Chung, B., & Hwang, S. (2016a). Automated hazardous area identification using laborers' actual and optimal routes. *Automation in Construction, 65*, 21–32. https://doi.org/10.1016/j.autcon.2016.01.006

Kim, H., & M, S., Lee, H., M, Park, M., Asce, M., Chung, B., Hwang, S., S M,. (2015). Information Retrieval Framework for Hazard Identification in Construction. *Journal of Computing in Civil Engineering, 04014052*, 1–10. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000340

Kim, K., Cho, Y., & Zhang, S. (2016b). Integrating work sequences and temporary structures into safety planning: Automated scaffolding-related safety hazard identi fi cation and prevention in BIM. *Automation in Construction, 70*, 128–142. https://doi.org/10.1016/j.autcon.2016.06.012

Kim, K., & Teizer, J. (2014). Advanced Engineering Informatics Automatic design and planning of scaffolding systems using building information modeling. *Advanced Engineering Informatics, 28*, 66–80. https://doi.org/10.1016/j.aei.2013.12.002

Kim, K., Cho, Y., & A M, Kim, Kinam,. (2018). BIM-Driven Automated Decision Support System for Safety Planning of Temporary Structures. *Journal of Construction Engineering and Management, 144*, 1–11. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001519

Kim, K., & M, Aff, Cho, Y.K., M, A, Kim, Kinam,. (2019). BIM-Based Decision-Making Framework for Scaffolding Planning. *Journal of Management Engineering*. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000656

Kim, Y., Hong, W., Park, J., Cha, G. (2017). An estimation framework for building information modeling (BIM) -based demolition waste by type. https://doi.org/10.1177/0734242X17736381

Kincelova, K., Boton, C., Blanchet, P., & Dagenais, C. (2020). Fire safety in tall timber building: A BIM-based automated code-checking approach. *Buildings*. https://doi.org/10.3390/BUILDINGS10070121

Klanšek, U.M.P. (2004). Cost Optimization of Construction Project 976–982.

Konyushkov, V., Sotnikov, S., Veretennikov, V., Ershov, I. (2020). Application of 4D BIM modelling in planning and construction of zero cycle works, in: E3S Web of Conferences. pp. 1–10.

Koo, B., & Fischer, M. (2000). Feasibility study of 4D CAD in commercial construction. *Journal of Construction Engineering & Management, 126*, 251.

Koseoglu, O. (2018). Mobile BIM implementation and lean interaction on construction site A case study of a complex airport project. *Engineering, Construction and Architectural Management, 25*, 1298–1321. https://doi.org/10.1108/ECAM-08-2017-0188

Koseoglu, O., Sakin, M., & Arayici, Y. (2018). Exploring the BIM and lean synergies in the Istanbul Grand Airport construction project. *Engineering, Construction and Architectural Management*, *25*(10), 1339–1354. https://doi.org/10.1108/ECAM-08-2017-0186.

Krasny, E., Klari, S., & Korjeni, A. (2017). Analysis and comparison of environmental impacts and cost of bio- based house versus concrete house. *Journal of Cleaner Production, 161*, 968–976. https://doi.org/10.1016/j.jclepro.2017.05.103

Kropp, C., Koch, C., & König, M. (2018). Interior construction state recognition with 4D BIM registered image sequences. *Automation in Construction, 86*, 11–32. https://doi.org/10.1016/j.autcon.2017.10.027

Kubicki, S., Guerriero, A., Schwartz, L., Daher, E., & Idris, B. (2019). Assessment of synchronous interactive devices for BIM project coordination: Prospective ergonomics approach. *Automation in Construction, 101*, 160–178. https://doi.org/10.1016/j.autcon.2018.12.009

Kumar, V., Viswanadham, N. (2007). A CBR-based Decision Support System Framework for Construction Supply Chain Risk Management. In: Proceedings of the 3rd Annual IEEE Conference on Automation Science and Engineering. pp. 980–985.

Kwok, J., Wong, W., Zhou, J., Ansah, M. K., Chen, X., Yang, H., Lu, L., Lam, P. T. I., Lu, Y., Wu, Z., Chang, R., Li, Y., Santos, R., Costa, A. A., Silvestre, J. D., Pyl, L., Chang, Y. T., & Hsieh, S. H. (2019). Building Information Modeling (BIM) for green buildings: A critical review and future directions. *Automation in Construction, 25*, 1–40. https://doi.org/10.1016/j.autcon.2019.02.022

Kwon, O., Park, C., & Lim, C. (2014). A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality. *Automation in Construction, 46*, 74–81. https://doi.org/10.1016/j.autcon.2014.05.005

Kymmell, W. (2008). Building Information Modelling: Planning and Managing Construction Project with 4D CAD and simulation. United State of America. Mc Graw Hill.

Lam, P., Wong, F., & Tse, K. (2010). Effectiveness of ICT for construction information exchange among multidisciplinary project teams. *Journal of Computing in Civil Engineering, 24*, 365–376. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000038

Latiffi, A. A., Brahim, J., & Fathi, M. S. (2014). The Development of Building Information Modeling (BIM) Definition. *Applied Mechanics and Materials*. https://doi.org/10.4028/www.scientific.net/AMM.567.625

Lawrence, M., Pottinger, R., Staub-french, S., & Prasad, M. (2014). Creating flexible mappings between Building Information Models and cost information. *Automation in Construction, 45*, 107–118. https://doi.org/10.1016/j.autcon.2014.05.006

Le, H. Q., & Hsiung, B. C. B. (2014). A novel mobile information system for risk management of adjacent buildings in urban underground construction. *Southeast Asian Geotechnical Society, 45*, 52–63.

Lee, J., Yang, H., Lim, J., Hong, T., & Kim, J. (2020). BIM-based preliminary estimation method considering the life cycle cost for decision-making in the early design phase. *Journal of Asian Architecture and Building Engineering, 19*, 384–399. https://doi.org/10.1080/13467581.2020.1748635

Lee, S., Kim, K., & Yu, J. (2014). BIM and ontology-based approach for building cost estimation. *Automation in Construction, 41*, 96–105. https://doi.org/10.1016/j.autcon.2013.10.020

Li, C. Z., Zhong, R. Y., Xue, F., Xu, G., Chen, K., Huang, G. G., & Shen, G. Q. (2017). Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction. *Journal of Cleaner Production, 165*, 1048–1062. https://doi.org/10.1016/j.jclepro.2017.07.156

Li, H., Lu, M., Hsu, S., Gray, M., & Huang, T. (2015). Proactive behavior-based safety management for construction safety improvement. *Safety Science, 75*, 107–117. https://doi.org/10.1016/j.ssci.2015.01.013

Lin, G., & Shen, Q. (2007). Measuring the Performance of Value Management Studies in Construction. *Critical Review, 23*, 2–9. https://doi.org/10.1061/(ASCE)0742-597X(2007)23

Lin, L., Huang, M., Li, J., Song, X., & Sun, Y. (2017). The Application and Exploration of the TSTL in Construction Management Based on BIM. *Journal of Applied Science and Engineering, 20*, 309–317. https://doi.org/10.6180/jase.2017.20.3.05

Lin, Y. (2015). Use of BIM approach to enhance construction interface management: A Case Study. *Journal of Civil Engineering and Management, 21*, 201–217. https://doi.org/10.3846/13923730.2013.802730

Lin, Y., Chang, J., & Su, Y. (2016). Developing construction defect management system using BIM technology in quality inspection. *Journal of Civil Engineering and Management, 22*, 903–914.

Lin, Y., Cheung, W., & Ph, D. (2020). Developing WSN / BIM-Based Environmental Monitoring Management System for Parking Garages in Smart Cities. *J. Manage. Eng, 36*, 1–17. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000760

Lin, Y., Yang, H., 2018. A Framework for Collaboration Management of BIM Model Creation in Architectural Projects. Journal of Asian Architecture and Building Engineering 39–46.

Lisha, A., Deng, Y., & Ren, M. (2018). Structural reconstruction design and performance simulation analysis of old buildings based on BIM. *International Journal of Low-Carbon Technologies, 13*, 255–259. https://doi.org/10.1093/ijlct/cty024

Liu, D., Chen, J., Hu, D., & Zhang, Z. (2019). Dynamic BIM-augmented UAV safety inspection for water diversion project. *Computers in Industry, 108*, 163–177. https://doi.org/10.1016/j.compind.2019.03.004

Liu, D., Ph, D., Asce, A. M., Jin, Z., Asce, S. M., Gambatese, J., Ph, D., & Asce, M. (2020). Scenarios for Integrating IPS – IMU System with BIM Technology in Construction Safety Control. *Practice Periodical on Structural Design and Construction, 25*, 1–7. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000465

Liu, H., Al-hussein, M., & Lu, M. (2015). Automation in Construction BIM-based integrated approach for detailed construction scheduling under resource constraints. *Automation in Construction, 53*, 29–43. https://doi.org/10.1016/j.autcon.2015.03.008

Liu, P. (2021). Mountain Rainfall Estimation and BIM Technology Site Safety Management Based on Internet of Things. *Mobile Information Systems, 2021*, 1–7. https://doi.org/10.1155/2021/1017200

Liu, R., & Hu, X. (2016). Case Study of Construction Cost Estimation in China Electric Power Industry Based on BIM Technology. *International Journal of Grid and Distributed Computing, 9*, 173–186.

Liu, Y., van Nederveen, S., & Hertogh, M. (2017). Understanding effects of BIM on collaborative design and constructionAn empirical study in China. *International Journal of Project Management, 35*, 686–698. https://doi.org/10.1016/j.ijproman.2016.06.007

Lu, W., Fung, A., Peng, Y., Liang, C., & Rowlinson, S. (2014a). Cost-bene fi t analysis of Building Information Modeling implementation in building projects through demystification of time-effort distribution curves. *Building and Environment, 82*, 317–327. https://doi.org/10.1016/j.buildenv.2014.08.030

Lu, Y., Li, Y., Skibniewski, M., Wu, Z., Wang, R., & Le, Y. (2014b). Information and communication technology applications in architecture, engineering, and construction organizations: A 15-year review. *Journal of Management Engineering*. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000319

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, 83*, 134–148. https://doi.org/10.1016/j.autcon.2017.08.024

Luo, H., Gong, P. (2015). A BIM-based Code Compliance Checking Process of Deep Foundation Construction Plans 549–576. https://doi.org/10.1007/s10846-014-0120-z

Ma, G., Wu, M., Wu, Z., & Yang, W. (2021). Single-shot multibox detector- and building information modeling-based quality inspection model for construction projects. *Journal of Building Engineering, 38*, 102216. https://doi.org/10.1016/j.jobe.2021.102216

Ma, Z., Cai, S., Mao, N., Yang, Q., Feng, J., & Wang, P. (2018). Construction quality management based on a collaborative system using BIM and indoor positioning. *Automation in Construction, 92*, 35–45. https://doi.org/10.1016/j.autcon.2018.03.027

Ma, Z., Wei, Z., & Zhang, X. (2013). Semi-automatic and specification-compliant cost estimation for tendering of building projects based on IFC data of design model. *Automation in Construction, 30*, 126–135. https://doi.org/10.1016/j.autcon.2012.11.020

Malacarne, G. (2018). Investigating benefits and criticisms of BIM for construction scheduling in SMES: AN ITALIAN CASE STUDY. *J. Sus. Dev. Plann., 13*, 139–150. https://doi.org/10.2495/SDP-V13-N1-139-150

Malekitabar, H., Ardeshir, A., Hassan, M., & Stouffs, R. (2016). Construction safety risk drivers: A BIM approach. *Safety Science, 82*, 445–455. https://doi.org/10.1016/j.ssci.2015.11.002

Martínez-aires, M. D., López-alonso, M., & Martínez-rojas, M. (2018). Building information modeling and safety management: A systematic review. *Safety Science, 101*, 11–18. https://doi.org/10.1016/j.ssci.2017.08.015

Martínez-rojas, M., Marín, N., & Vila, M. A. (2016). *The Role of Information Technologies to Address Data Handling in Construction Project Management, 30*, 1–20. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000538

Martínez-Rojas, M., del Carmen Pardo-Ferreira, M., & Rubio-Romero, J. C. (2018). Twitter as a tool for the management and analysis of emergency situations: A systematic literature review. *International Journal of Information Management*, *43*, 196–208. https://doi.org/10.1016/j.ijinfomgt.2018.07.008

Marzouk, M., & Abubakr, A. (2016). support for tower crane selection with building information models and genetic algorithms. *Automation in Construction, 61*, 1–15. https://doi.org/10.1016/j.autcon.2015.09.008

Marzouk, M., & Al Daour, I. (2018). Planning labor evacuation for construction sites using BIM and agent-based simulation. *Safety Science, 109*, 174–185. https://doi.org/10.1016/j.ssci.2018.04.023

Mashayekhi, A., & Heravi, G. (2020). A decision-making framework opted for smart building' s equipment based on energy consumption and cost trade-off using BIM and MIS. *Journal of Building Engineering, 32*, 101653. https://doi.org/10.1016/j.jobe.2020.101653

Mejlænder-larsen, Ø. (2018). A three-step process for reporting progress in detail engineering using BIM, based on experiences from oil and gas projects. *Engineering, Construction and Architectural Management, 26*, 648–667. https://doi.org/10.1108/ECAM-12-2017-0273

Melzner, J., Zhang, S., Teizer, J., & Bargstädt, H. (2013). A case study on automated safety compliance checking to assist fall protection design and planning in building information models A case study on automated safety compliance checking to assist fall protection design and planning in building information mo. *Construction Management and Economics ISSN*. https://doi.org/10.1080/01446193.2013.780662

Memon, A.H., Rahman, I., Razaki, M., Asmi, A., Aziz, A. (2011). Time Overrun in Construction Projects from the Perspective of Project Management Consultant (PMC). Journal of Surveying, Construction and Property 2, 54–66. https://doi.org/10.22452/jscp.vol2no1.4

Mihić, M., Cerić, A., Završki, I. (2018). Developing Construction Hazard Database for Automated Hazard Identification Process. Tehnički vjesnik 1761–1769.

Mikulakova, E., König, M., Tauscher, E., & Beucke, K. (2010). Knowledge-based schedule generation and evaluation. *Advanced Engineering Informatics, 24*, 389–403. https://doi.org/10.1016/j.aei.2010.06.010

Mills, A., Love, P. E. D., & Williams, P. (2009). *Defect Costs in Residential Construction, 135*, 12–17.

Mirahadi, F., Mccabe, B., & Shahi, A. (2019). IFC-centric performance-based evaluation of building evacuations using fire dynamics simulation and agent-based modeling. *Automation in*

Construction, 101, 1–16. https://doi.org/10.1016/j.autcon.2019.01.007

Mittas, N., Mamalikidis, I., & Angelis, L. (2015). A framework for comparing multiple cost estimation methods using an automated visualization toolkit. *Information and Software Technology, 57*, 310–328. https://doi.org/10.1016/j.infsof.2014.05.010

Moayeri, V., Moselhi, O., Zhu, Z. (2017). BIM-based model for quantifying the design change time ripple effect. NRC Research Press 642, 626–642. https://doi.org/10.1139/cjce-2016-0413

Mohamed, D., Srour, F., Tabra, W., & Zayed, and T.,. (2009). *A Prediction Model for Construction Project Time Contingency, in Construction Research Congress*. ASCE. https://doi.org/10.1061/41020(339)75

Moon, H., Dawood, N., & Kang, L. (2014a). Development of workspace conflict visualization system using 4D object of work schedule. *Advanced Engineering Informatics, 28*, 50–65. https://doi.org/10.1016/j.aei.2013.12.001

Moon, H., Kim, H., Kamat, V. R., & Kang, L. (2015). BIM-based construction scheduling method using optimization theory for reducing activity overlaps. *Journal of Computing in Civil Engineering*. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000342

Moon, H., Kim, H., Kim, C., & Kang, L. (2014b). Development of a schedule-workspace interference management system simultaneously considering the overlap level of parallel schedules and workspaces. *Automation in Construction, 39*, 93–105. https://doi.org/10.1016/j.autcon.2013.06.001

Mosavi, A., Bathla, Y., & Varkonyi-Koczy, and A.,. (2018). Predicting the Future Using Web Knowledge: State of the Art Survey. *Advances in Intelligent Systems and Computing, 660*, 342–344.

Nawari, N. O. (2012). BIM Standard in Off-Site Construction. *J. Architect. Eng, 18*, 107–113. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000056

Nguyen, T.A., Do, S.T., Pham, T.-A., Nguyen, M.C. (2021). Application of BIM and 3D laser scanning for quantity surveying and quality management in construction projects. p. 030003. https://doi.org/10.1063/5.0070845

Nhi, N., Tran, T. (2020). 4D BIM Workspace Conflict Detection for Occupational Management A Case Study for Basement Construction Using Bottom Up Method, in: ICEBT. pp. 72–77.

Niknam, M., & Karshenas, S. (2015). Integrating distributed sources of information for construction cost estimating using Semantic Web and Semantic Web Service technologies. *Automation in Construction, 57*, 222–238. https://doi.org/10.1016/j.autcon.2015.04.003

Niu, Y., Lu, W., Chen, K., Huang, G. G., & Anumba, C. (2016). Smart Construction Objects. *Journal of Computing in Civil Engineering*. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000550

Oh, M., Lee, J., Wan, S., & Jeong, Y. (2015). Integrated system for BIM-based collaborative design. *Automation in Construction, 58*, 196–206. https://doi.org/10.1016/j.autcon.2015.07.015

Oladinrin, T.O., Ogunsemi, D.R., Aje, I.O. (2012). Role of Construction Sector in Economic Growth. Empirical Evidence from Nigeria. African Journal Online, Volume 7, No 1.

Oraee, M., Hosseini, M. R., Papadonikolaki, E., Palliyaguru, R., & Arashpour, M. (2017). Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. *International Journal of Project Management, 35*, 1288–1301. https://doi.org/10.1016/j.ijproman.2017.07.001

Pantano, E., Rese, A., & Baier, D. (2017). Journal of Retailing and Consumer Services Enhancing the online decision-making process by using augmented reality: A two country comparison of youth markets. *Journal of Retailing and Consumer Services, 38*, 81–95. https://doi.org/10.1016/j.jretconser.2017.05.011

Papagiannidis, S., Pantano, E., & See-to, E. W. K. (2013). and users' product purchasing intentions Modelling the determinants of a simulated experience in a virtual retail store and users ' product purchasing intentions. *Journal of Marketing Management, 29*, 1462–1492. https://doi.org/10.1080/0267257X.2013.821150

Park, C., & Kim, H. (2013). A framework for construction safety management and visualization system. *Automation in Construction, 33*, 95–103. https://doi.org/10.1016/j.autcon.2012.09.012

Park, C., Lee, D., Kwon, O., & Wang, X. (2013). A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. *Automation in Construction, 33*, 61–71. https://doi.org/10.1016/j.autcon.2012.09.010

Park, J., Asce, S. M., Cai, H., Asce, M., & Perissin, D. (2018). Bringing Information to the Field: Automated Photo Registration and 4D BIM. *Journal of Computing in Civil Engineering*. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000740

Park, J., & M, S., Cai, H., M, Dunston, P.S., A M,. (2017). Database-Supported and Web-Based Visualization for Daily 4D BIM. *Journal of Construction Engineering and Management, 143*, 1–12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001392

Park, J., & M, S., Kim, K., Cho, Y.K., A M,. (2017). Framework of Automated Construction-Safety Monitoring Using Cloud-Enabled BIM and BLE Mobile Tracking Sensors. *Journal of Construction Engineering and Management, 143*, 1–12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001223

Park, S., & Kim, I. (2015). BIM-based quality control for safety issues in the design and construction phases. *International Journal of Architectural Research, 9*, 111–129.

PASC (2020). Applying predictive analytics in construction.

Pathirage, S.K., Underwood, J. (2015). The importance of integrating cost management with building information modeling (BIM). In: International Postgraduate Research Conference. University of Salford, pp. 10–12.

Popov, V., Juocevicius, V., Migilinskas, D., Ustinovichius, L., & Mikalauskas, S. (2010). The use of virtual building design and construction model for developing an effective project concept in 5D environment. *Automation in Construction, 19*, 357–367.

Porwal, A., Parsamehr, M., Szostopal, D., Ruparathna, R., & Hewage, K. (2020). The integration of building information modeling (BIM) and system dynamic modeling to minimize construction waste generation from change orders. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2020.1854930

Pour, F., Seyedzadeh, S., Oliver, S., & Rodriguez, S. (2020). On-demand monitoring of construction projects through a game-like hybrid application of BIM and machine learning. *Automation in Construction, 110*, 103012. https://doi.org/10.1016/j.autcon.2019.103012

Qi, J, Issa, R., Olbina, S., Hinze, J., 2014a. Use of building information modeling in design to prevent construction worker falls. J. Comput. Civ. Eng.

Qi, J., Issa, R. R. A., Asce, F., Olbina, S., Asce, A. M., Hinze, J., & Asce, M. (2014b). Use of Building Information Modeling in Design to Prevent Construction Worker Falls. *Journal of Computing in Civil Engineering, 28*, 1–10. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000365

Raicu, A., Oanta, E., & Sabau, A. (2017). Making objective decisions in mechanical engineering problems. *Materials Science and Engineering*. https://doi.org/10.1088/1757-899X/227/1/012108

Rajguru, A. (2016). Effective Techniques In Cost Optimization Of Construction Projects. *International Journal of Informative & Futuristic Research, 3*, 1646–1658.

Chavada, R., Dawood, N., & Kassem, M. (2012). Construction workspace management: The development and application of a novel nD planning approach and tool. *Journal of Information Technology in Construction, 17*, 213–236.

Rebolj, D., Pu, Z., Nenad, Č, Bizjak, M., & Mongus, D. (2017). Point cloud quality requirements for Scan-vs-BIM based automated construction progress monitoring. *Automation in Construction, 84*, 323–334. https://doi.org/10.1016/j.autcon.2017.09.021

Rezgui, Y., Boddy, S., Wetherill, M., & Cooper, G. (2011). Past, present and future of information and knowledge sharing in the construction industry: Towards semantic service-based e-construction. *Computer-Aided Design, 43*, 502–515.

Riaz, Z., Arslan, M., Kiani, A. K., & Azhar, S. (2014). CoSMoS : A BIM and wireless sensor based integrated solution for worker safety in con fi ned spaces. *Automation in Construction, 45*, 96–106. https://doi.org/10.1016/j.autcon.2014.05.010

Rounce, G. (1998). Quality, waste and cost considerations in architectural building design management 16, 123–127.

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners. *Designers, Engineers, Contractors, and Facility Managers*. https://doi.org/10.1002/9781119287568

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, 103*, 221–234. https://doi.org/10.1016/j.autcon.2019.02.022

Sardroud, J. M. (2015). Perceptions of automated data collection technology use in the construction industry". *Journal of Computing in Civil Engineering., 21*, 54–66.

Sebastian, R. (2011). Changing Roles of the Clients Architects and Contractors Trough BIM. *Engineering Construction and Architectural Management, 18*, 176–187.

Shahi, A., Safa, M., Haas, C. T., & F, West, J.S., M,. (2015). Data Fusion Process Management for Automated Construction Progress Estimation. *Journal of Computing in Civil Engineering, 29*, 1–9. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000436

Shan, R., Xiao, X., Luan, J., Guo, Y., & Kang, Q. (2018). Whole Process Cost Management Control of Dangerous Chemical Product Construction Projects. *The Italian Association of Chemical Engineering, 71*, 1279–1284. https://doi.org/10.3303/CET1871214

Shane, J. S., Asce, A. M., Molenaar, K. R., Asce, M., Anderson, S., Asce, M., Schexnayder, C., & Asce, D. M. (2009). *Construction Project Cost Escalation Factors, 25*, 221–229. https://doi.org/10.1061/(ASCE)0742-597X(2009)25

Sheikhkhoshkar, M., Rahimian, F. P., Kaveh, M. H., Hosseini, M. R., & Edwards, D. J. (2019). Automated planning of concrete joint layouts with 4D-BIM. *Automation in Construction, 107*, 102943. https://doi.org/10.1016/j.autcon.2019.102943

Shen, Z., & Issa, R. (2010). Quantitative evaluation of the BIM-assisted construction detailed cost estimates. *Journal of Information Technology in Construction, 15*, 234–257.

Smith, P. (2014). BIM implementation - Global strategies. *Procedia Engineering, 85*, 482–492. https://doi.org/10.1016/j.proeng.2014.10.575

Song, S., Yang, J., & Kim, N. (2012). Computers in Industry Development of a BIM-based structural framework optimization and simulation system for building construction §. *Computers in Industry, 63*, 895–912. https://doi.org/10.1016/j.compind.2012.08.013

Staub-french, S., Fischer, M., Kunz, J. (2002). An Ontology for Relating Features.

Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction, 18*, 357–375. https://doi.org/10.1016/j.autcon.2008.10.003

Succar, B., & Kassem, M. (2015). Macro-BIM adoption: Conceptual structures. *Automation in Construction, 57*, 64–79. https://doi.org/10.1016/j.autcon.2015.04.018

Sun, C., Man, Q., & Wang, Y. (2015). Study on BIM-based construction project cost and schedule risk early warning. *Journal of Intelligent & Fuzzy Systems, 29*, 469–477. https://doi.org/10.3233/IFS-141178

Teizer, J. (2015). Advanced Engineering Informatics Status quo and open challenges in vision-based sensing and tracking of temporary resources on infrastructure construction sites. *Advanced Engineering Informatics, 29*, 225–238. https://doi.org/10.1016/j.aei.2015.03.006

Teo, E., Lin, A., Ofori, G., Tjandra, I., & Kim, H. (2017). *Framework for Productivity and Safety Enhancement System Using BIM in Singapore*. https://doi.org/10.1108/ECAM-05-2016-0122

Tezel, A., Taggart, M., Koskela, L., Tzortzopoulos, P., Hanahoe, J., & Kelly, M. (2020). Lean construction and BIM in small and medium-sized enterprises (SMEs) in construction: A systematic literature review. *Canadian Journal of Civil Engineering, 47*, 186–201. https://doi.org/10.1139/cjce-2018-0408

Timberline (2001). Precision Estimating Extended and CAD Integrator.

Tresidder, M. (2018). Briefing: Design for manufacture and off-site construction at Woolston Wastewater Treatment Works (UK) 171, 137–140.

Trost, S. M., Asce, M., Oberlender, G. D., & Asce, F. (2003). *Predicting Accuracy of Early Cost Estimates Using Factor Analysis and Multivariate Regression, 129*, 198–204. https://doi.org/10.1061/(ASCE)0733-9364(2003)129

Turkan, Y., Bosche, F., Haas, C. T., & Haas, R. (2012). Automated progress tracking using 4D schedule and 3D sensing technologies. *Automation in Construction, 22*, 414–421. https://doi.org/10.1016/j.autcon.2011.10.003

Turner, R., Huemann, M., & Keegan, A. (2008). Human resource management in the project-oriented organization: Employee well-being and ethical treatment. *International Journal of Project Management, 26*, 577–585. https://doi.org/10.1016/j.ijproman.2008.05.005

Vandenbergh, T., & Pyl, L. (2020). BIM-based life cycle assessment and life cycle costing of an office building in Western Europe. *Building and Environment*. https://doi.org/10.1016/j.buildenv.2019.106568

Vanlande, R., Nicolle, C., & Cruz, C. (2008). IFC and building lifecycle management. *Automation in Construction, 18*, 70–78.

Vitiello, U., Ciotta, V., Salzano, A., Asprone, D., Manfredi, G., & Cosenza, E. (2019). Automation in Construction BIM-based approach for the cost-optimization of seismic retro fi t strategies on existing buildings. *Automation in Construction, 98*, 90–101. https://doi.org/10.1016/j.autcon.2018.10.023

Wang, C., Cho, Y. K., & Kim, C. (2015a). Automatic BIM component extraction from point clouds of existing buildings for sustainability applications. *Automation in Construction, 56*, 1–13. https://doi.org/10.1016/j.autcon.2015.04.001

Wang, H., & Song, X. (2016). Research on BIM Construction Schedule Generating Algorithm. International Journal of Simulation – Systems. *Science & Technology, 16*, 1–7. https://doi.org/10.5013/IJSSST.a.16.1B.10

Wang, J., Zhang, S., & Teizer, J. (2015b). Geotechnical and safety protective equipment planning using range point cloud data and rule checking in building information modeling. *Automation in Construction, 49*, 250–261. https://doi.org/10.1016/j.autcon.2014.09.002

Wang, K., Wang, W., Wang, H., Hsu, P., Wu, W., & Kung, C. (2016). Applying building information modeling to integrate schedule and cost for establishing construction progress curves. *Automation in Construction, 72*, 397–410. https://doi.org/10.1016/j.autcon.2016.10.005

Wang, Q., Sohn, H., M., Cheng, J.C.P., A.M. (2018). Automatic As-Built BIM Creation of Precast Concrete Bridge Deck Panels

Using Laser Scan Data 32, 1–17. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000754
Wang, Y., Wang, X., Wang, J., Yung, P., & Jun, G. (2013). Engagement of facilities management in design stage through BIM: Framework and a case study. *Advances in Civil Engineering*. https://doi.org/10.1155/2013/189105
Wang, Y., Yu, S., Ma, N., Wang, J., Hu, Z., Liu, Z., & He, J. (2020). Prediction of product design decision Making: An investigation of eye movements and EEG features. *Advanced Engineering Informatics, 45*, 101095. https://doi.org/10.1016/j.aei.2020.101095
Wang, Z. (2019). BIM-based draft schedule generation in reinforced concrete-framed buildings. Construction Innovation 19, 280–294. https://doi.org/10.1108/CI-11-2018-0094
Wehbe, R., & Shahrour, I. (2021). A bim-based smart system for fire evacuation. *Future Internet*. https://doi.org/10.3390/fi13090221
Wells, J. (1985). The Role of Construction in Economic Growth and Development. *Habitat International, 9*, 55–70.
Williams, T. P., & Gong, J. (2014). Predicting construction cost overruns using text mining, numerical data and ensemble classi fi ers. *Automation in Construction, 43*, 23–29. https://doi.org/10.1016/j.autcon.2014.02.014
Wong, J., Wang, X., Li, H., Chan, G., & Li, H. (2014). A review of cloud-based bim technology in the construction sector. *Journal of Information Technology in Construction, 19*, 281–291.
Wu, S. (2021). Research on the Method of Engineering Project Schedule Control Based on BIM Technology. *IOP Conference Series: Earth and Environmental Science, 676*, 012046. https://doi.org/10.1088/1755-1315/676/1/012046
Wu, W., Ren, C., Wang, Y., Liu, T., & Li, L. (2018). DEA-Based Performance Evaluation System for Construction Enterprises Based on BIM Technology. *Journal of Computing in Civil Engineering, 32*, 1–10. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000722
Xue, X., Shen, Q., & Ren, Z. (2010). Critical Review of Collaborative Working in Construction Projects: Business Environment and Human Behaviors. *Journal of Management in Engineering, 26*, 196–208. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000025
Xu, S., Liu, K., Tang, L. C. M., & Li, W. (2016). A framework for integrating syntax, semantics and pragmatics for computer-aided professional practice: With application of costing in construction industry. *Computers in Industry, 83*, 28–45. https://doi.org/10.1016/j.compind.2016.08.004
Yan, Y., 2017. Research and application of BIM technology in the design of prefabricated and assembled concrete structures.
Yang, J. (2021). Application of BIM Technology in Construction Cost Management of Building Engineering. *Journal of Physics: Conference Series, 2037*, 012046. https://doi.org/10.1088/1742-6596/2037/1/012046
Yu, W., Zeng, L., Hong, D., Wang, X. (2021). Research and Development of Building Construction Safety Management System Based on BIM Technology, in 2021 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS). IEEE, pp. 137–140. https://doi.org/10.1109/ICITBS53129.2021.00043
Yun, S. (2021). Analysis of Cost Estimation Level from BIM Model and Development of QDB based Integrated Cost Management Model. Turkish Journal of Computer and Mathematics Education (TURCOMAT) 12, 659–665. https://doi.org/10.17762/turcomat.v12i6.2064
Zhang, H. (2020). Design and Implementation of BIM-based Fire Risk Assessment System. *Journal of Physics: Conference Series, 1584*, 1–8. https://doi.org/10.1088/1742-6596/1584/1/012064
Zhang, J. P., & Hu, Z. Z. (2011). BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. *Principles and Methodologies. Automation in Construction, 20*, 167–180. https://doi.org/10.1016/j.autcon.2010.09.014
Zhang, S., Boukamp, F., & Teizer, J. (2015a). Ontology-based semantic modeling of construction safety knowledge: Towards automated safety planning for job hazard analysis (JHA). *Automation in Construction, 52*, 29–41. https://doi.org/10.1016/j.autcon.2015.02.005
Zhang, S., Sulankivi, K., Kiviniemi, M., Romo, I., Eastman, C. M., & Teizer, J. (2015b). BIM-based fall hazard identification and prevention in construction safety planning. *Safety Science, 72*, 31–45. https://doi.org/10.1016/j.ssci.2014.08.001
Zhang, S., Teizer, J., Lee, J., Eastman, C. M., & Venugopal, M. (2013). Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Automation in Construction, 29*, 183–195. https://doi.org/10.1016/j.autcon.2012.05.006
Zhang, S., Teizer, J., Pradhananga, N., & Eastman, C. M. (2015c). Workforce location tracking to model, visualize and analyze workspace requirements in building information models for construction safety planning. *Automation in Construction, 60*, 74–86. https://doi.org/10.1016/j.autcon.2015.09.009
Zheng, M. Y., Song, J. L., & Peng, Q. C. (2013). Analysis of Carbonization Mechanism in ULCS Continuous Casting and Control Measures. *Advanced Materials Research, 739*, 214–217.
Zhiliang, M., Zhenhua, W., Wu, S., & Zhe, L. (2011). Application and extension of the IFC standard in construction cost estimating for tendering in China. *Automation in Construction, 20*, 196–204. https://doi.org/10.1016/j.autcon.2010.09.017
Zhou, W., Whyte, J., & Sacks, R. (2012). Construction safety and digital design: A review. *Automation in Construction, 22*, 102–111. https://doi.org/10.1016/j.autcon.2011.07.005
Zhu, Y. (2013). The construction safety accident emergency decision support system based on ontology and CBR. *Applied Mechanics and Materials, 426*, 2149–2153. https://doi.org/10.4028/www.scientific.net/AMM.423-426.2149
Ziwei Wang, E.R.A., 2019. BIM-based draft schedule generation in reinforced concrete-framed buildings. Construction Innovation 19.