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Implementation of Building Information Modelling in infrastructure construction projects: a study of dimensions and strategies

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Abstract:
The emergence of Building Information Modelling (BIM) has revolutionized the infrastructure construction industry by introducing real-time and collaborative information management tools to be used throughout the lifecycle of projects. The importance of BIM in this industry has been emphasized in previous research. However, strategies for the implementation of this system is still less explored, which requires more elaboration and validation. The purpose of this paper is to investigate such strategies considering all necessary dimensions of the BIM system in infrastructure construction projects. The findings are based on theoretical discussion and semi-structured interviews in a case study project in New South Wales, Australia. The results revealed that BIM integrates various elements of infrastructure construction, which include but are not limited to risk, time, cost, energy, safety, and sustainability. It was found that implementation strategies should focus on improving the contribution of the BIM system to infrastructure construction in terms of improved (1) integrity and automation, (2) collaboration, and (3) optimization. Identification of seven technical and managerial implementations strategies is the core contribution of this research. These strategies provide practitioners with insight into technical and managerial measures to be taken for the successful implementation of the BIM system.

Keywords:
information systems; Building Information Modelling; BIM; BIM dimensions; construction project delivery; construction industry.

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1. Introduction

Infrastructure as the building block of industrial and urban development benefits from information systems to address complexities. Proper use of modern information technology tools enhances cross-organizational and cross-departmental communications and provides a robust basis for collaborative design and construction. Introducing modern information systems improves agility in decision making and project delivery by reducing lead time [1]. The demonstrated impact of information systems on automated cost analysis [2], safety management practices [3], and management of operation and maintenance during the facility lifecycle [4] have encouraged construction organizations to implement different forms of information systems. Computer-aided design (CAD) is one of the prerequisites of automation in construction projects and information systems significantly contribute to distributing graphical representations of a facility [5] with stakeholders in a three-dimensional setting [6]. Information systems contribute to more effective management of project documentation and keeping up-to-date records of key project documents such as drawings, contracts, charters, and plans [7]. In large infrastructure projects, instant distribution of performance information among different stakeholders enables them to liaise with clients more effectively to coordinate actions for implementing sustainability initiatives [8] and construction plans [9].

With numerous stakeholders and technologies involved in the execution and delivery of infrastructure projects, the need for employing information systems is becoming more evident since they capacitate clients and contractors to enhance their communication and information exchange capacities [10]. Information systems provide a suitable basis for collecting, processing, storing, and sharing data related to the construction and operation of a facility. They contribute to the more agile management of data generated during this process [11]. The visualization and analysis of the information obtained from different teams involved in the process of infrastructure construction enable main contractors to identify errors and shortcomings of project plans, engineering designs, and architectural drawings before initiating the construction activities [8]. The dissemination of computer-aided design in these activities benefits contractors in terms of higher integration of design features with construction steps so that the possible conflicts and errors in the delivery stage are controlled. Integrated information systems store important data from each discipline and interlink them to ensure that all technical requirements of a facility have been incorporate early in the design and configuration stage [12].

The emergence of the Building Information Modelling (BIM) system restructured the mechanisms of collecting, analysing, and transmitting information among construction stakeholders [2]. With the ever-increasing importance of agile and lean construction methods, information technology tools are being frequently discussed in light of building information modelling (BIM) as an integrated platform allowing the interdisciplinary link of subsystems and building engineering mechanisms. Today’s construction industry is in an important era to drive a shift in the infrastructure construction sector from traditional methods to more systematic and advanced technologies. The dynamic and competitive construction market has led contractors to execute several projects simultaneously and deliver them with the highest quality to maintain their position in the market. Previous research underlined the importance of BIM in construction projects and highlighted its capabilities in coordinated design, production, communication, and data analysis [5]. The focus of prior studies was mainly to study specific aspects of building information modelling. Among such studies, it is noteworthy to acknowledge novel studies conducted by Montiel-Santiago et al. [8] that analysed the energy efficiency of buildings using BIM systems or the study conducted by Hassan et al. [2] on the application of five-dimensional BIM in improving construction estimations.

Although former studies endeavoured to determine the role of BIM in the construction industry, further research would consider examining the contribution of the BIM system and the potential strategies for implementing this system in infrastructure construction projects. This gap justifies undertaking a dedicated study to further elaborate on prerequisites and initiatives for achieving more effective BIM systems in the infrastructure sector. The current study aims to consolidate perspectives of prior studies and adds the viewpoints of experts on (1) the contribution of each possible dimension of the BIM system to infrastructure construction project delivery, as well as (2) potential strategies to implement the BIM system in infrastructure construction projects. The role of BIM is highlighted to explain how this system helps managers anticipate potential issues throughout all stages of design and construction through a digital representation of building characteristics.

The content of this paper has been structured as follows. The literature review section explains the theoretical background and concepts of BIM. The dimensions of BIM, success factors for effective implementation of this system, as well as the information systems needed for implementation of BIM are explained based on the findings of prior studies. The methods section explains the methodological approach used for data collection and analysis. The findings of the study were explained thereafter in terms of (1) the contribution of the BIM dimensions to infrastructure construction and (2) strategies for the implementation of the BIM system. The findings were followed by the discussion and conclusion section to discuss and conclude the main findings.

2. Literature review

2.1 Dimensions of Building Information Modelling

As a result of the literature survey, it was revealed that 10 dimensions characterize the full functionality of a BIM system. Figure 1 provides an overview of the dimensions of the BIM system and the incorporation of the important aspects of construction projects. The dimensions 1D to 7D have been in place since the early 2000s by using proper software packages [6]. However, 8D to 10D still need more elaboration and development to be used by companies in the infrastructure construction sector. In the simplest form, BIM documents procedures and important technical specifications of a facility while a sophisticated BIM system is capable of integrating important aspects of construction project delivery such as safety, lean construction, and automation [1].

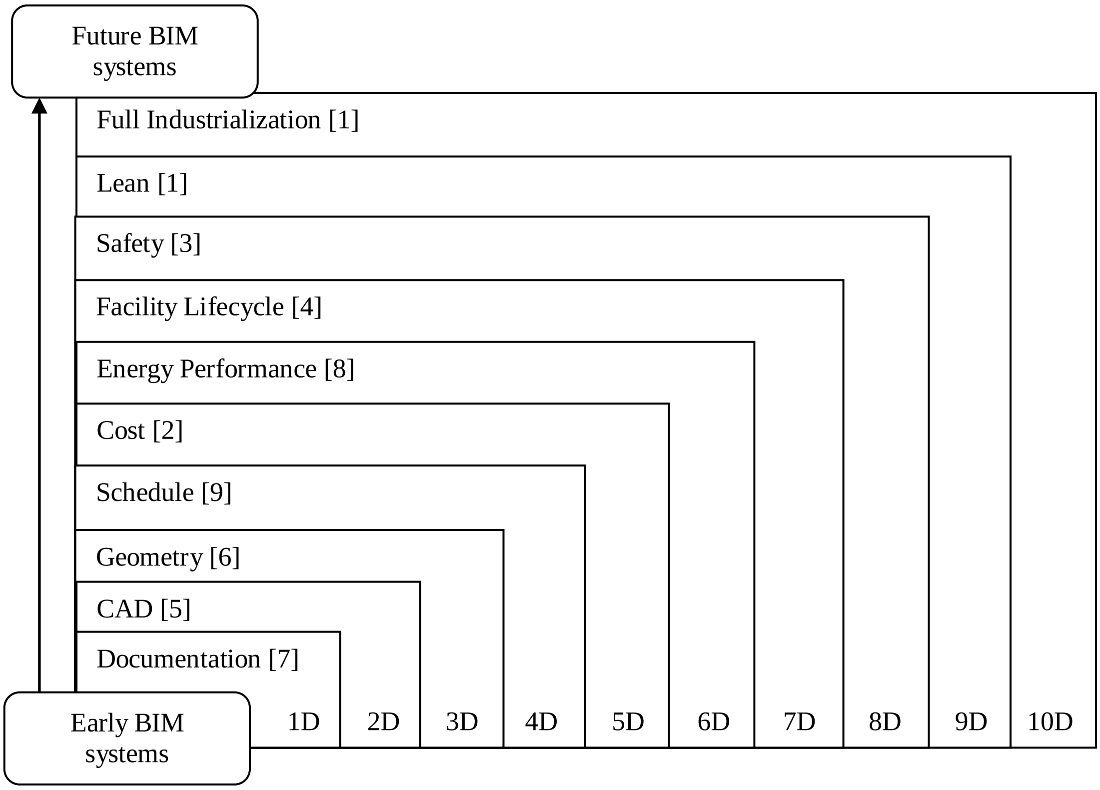

Figure 1: The dimensions of the BIM system

1D BIM: The preliminary foundation of BIM is the documentation of all requirements associated with the construction project lifecycle. The dispersed information from stakeholders and teamwork is integrated into the BIM platform to form a basis for managing changes to configuration and documents. Documentation clarifies the process of producing and sharing important information during the commissioning period of the infrastructure construction project. The structured set of project documents facilitates the information management process and enables project managers to exchange information among the project team members and keep them on track with consistent access to engineering specifications, architectural drawings, features of the equipment, and product requirements [7]. Proper document management is a prerequisite to processing changes and keeping records of different versions of documents. The access of internal and external stakeholders to documents is defined in the document management system, allowing real-time access to a comprehensive archive. The centralization of all important documents essential for planning, delivery, and management of a facility helps owners to gain deep insight into the dimension of information and its distribution among stakeholders. This aspect of BIM streamlines various stages of the infrastructure construction process.

2D BIM: Modelling a project in two dimensions is limited to a simple X-axis and Y-axis representation of project design and drawings. Planning is primarily conducted in two dimensions and relates constraints and objectives to the project specifications. 2D BIM, as the earliest form of construction models, allows fundamental planning activities to be performed faster and in a simpler format. However, in large and complex infrastructure projects, more elaboration is needed to ensure that cost-effective flawless plans and designs are generated and in place to support on-target construction project delivery. With the inclusion of more variables and constraints, detailed planning becomes more complicated and the need for visualizing the parameters arises [5].

3D BIM: Undertaking design and planning in a three-dimensional environment increases the clarity and rigour of the process. It entails integration and visualization of the graphical and non-graphical information ranging from space relationships and isometrics to estimated quantities [13]. Possible physical clashes in the construction of different components are simulated and designers can improve the quality of the outcomes. This is a kind of quality assurance for the design documents that removes errors and increases the compliance of projects with quality standards. Any updates such as further developments, changes, and demolition can be managed in a more organized way. The 3D BIM is an aid for stakeholders to coordinate their multidisciplinary activities and analyse structural features of the components. Accurate data on three aspects of the model is collected and stored in a database to be used in stages of the lifecycle. The 3D BIM adds space to the traditional 2D CAD (Computer-Aided Design) drawings and provide more profound insight into the graphical features of a facility. As a virtual representation of the visual details of a facility, 3D BIM helps architects to identify conflicts in the design documents. Pre-construction visualization is the best risk avoidance strategy to decrease major conflicts of design features during the stages of constructing a new facility [6].

4D BIM: Incorporation schedule into the 3D model of a facility enables detecting errors in timing and the sequence of activities. Project schedules are to be rigorously checked against any conflicts and interferences in the hard or soft logic of the activity dependencies that seem problematic. The progression of the scheduled activities is simulated using the BIM analytical tools so that the activity network can be optimized and improved. Sequential development of the installations, excavations, and other construction activities, as well as the lags such as curing time, is demonstrated throughout this process to ensure constructability and consistency of schedules. Adding another dimension to the graphical 3D model of the facility, a more accurate schedule is developed after construction phasing simulation and rectifying operational inefficiencies as well as logistical issues [9].

5D BIM: This dimension of BIM incorporates cost estimates into 4D BIM to enable integrated cost planning and project budgeting. The budget software, scheduling software, and BIM 3D model interoperate seamlessly so that estimators can analyse capital and operating costs during the construction stages. The sensitivity of the costs involved in the execution of each activity is analysed visually over time, which allows automated quantity surveying towards achieving a realistic budget. This tool can be used during the stages of infrastructure construction by keeping track of budget deviations from the baseline target. Elements of the 5D BIM should capable of extracting and visualizing accurate cost-related information that can be shared among estimators, owners, investors, and contractors [2].

6D BIM: The 6D BIM optimizes energy consumption and reduces the long-term costs associated with running the facility and improves performance. This dimension of BIM significantly contributes to sustainability objectives and creating a green infrastructure by conserving energy in the infrastructure construction sector. Accurate prediction of energy construction requirements and upfront costs of projects gives insight into the entire costs of managing a facility, which helps designers to adopt a long-term view of engineering specifications. A sensitivity analysis can be used to minimize the energy consumption of a facility to ensure the optimal and effective energy performance of the buildings. The energy management tools simulate the energy behaviour of a facility in the long run [8].

7D BIM: The literature does not draw a tight boundary around 6D and 7D. Further elaboration on the associated tools indicates that 7D BIM includes more lifecycle-related information necessary for achieving energy efficiency and sustainability throughout the lifecycle. Any information which is important for the operation and maintenance of the facility from design to demolition is integrated into 6D BIM to constitute 7D BIM. The information includes asset attributes, operation and maintenance details during the project commissioning period, specifications for the facility, installation and warranty details, maintenance schedules, manuals, and configurations of the equipment that are necessary for optimal performance. Owners can use such information for optimizing the operation and maintenance of the infrastructure towards achieving sustainability objectives. The 7D BIM helps managers visualize the lifetime cost of facilities and make informed decisions considering all lifetime impacts of their decisions on the development or changes in the facility. The lifecycle information is used to enable designers to consider the Total Cost of Ownership (TCO) in infrastructure planning [4].

8D BIM: The eighth dimension of BIM deals with the integration of onsite health and safety requirements into 7D BIM to ensure the safety of all personnel both during the stages of construction and the operation of the facility. This dimension enables managers to interact with the stakeholders and communicate seamlessly to execute safety plans from early stages in the facility lifecycle. Engineering designers could anticipate all preventive actions and key components in the design of the facility so that safety risks are minimized. This dimension aims to prevent accidents and design-related safety issues early in the planning and design phase. However, this aspect of the BIM systems has not been fully implemented in practice, and still, more effective tools and software are needed to perform this integration. 8D BIM could detect and eliminate the safety risk through visual analysis of the facility and its components [3].

9D BIM: The integration of lean construction requirements into 8D BIM forms the 9D BIM as a robust potential tool for more effective delivery and operation of a facility with the optimal use of resources and capital [1]. This dimension emphasizes the resource management techniques to improve the allocation and use of materials, labour, equipment, and tools during the facility lifespan. 9D BIM analyses all resources involved in the process of constructing and operating infrastructure. For example, useful insights can be gained for optimal use of trucks for the transport of materials, reducing the number of onsite vehicles and circulation roads, eliminating repetitive non-value adding tasks, and reducing cycle time.

10D BIM: The 10D BIM is another prospective dimension of the BIM system that aims to take the advantage of industrialized construction and incorporates disaster management plans [1]. This dimension identifies and eliminates obstacles to productivity throughout the design, construction, and delivery of a facility. To improve the productivity level, this dimension encourages the use of drones and manufacturing machines. Artificial intelligence plays an important role in this domain to automate engineering planning and control procedures. This dimension has been introduced recently and its application is yet to be further explored and tested. Incorporating a higher level of automation and systematic control into infrastructure construction increases the rigour of this process and minimizes the harmful impacts on the environment by employing instant information management.

2.2 Success factors for the implementation of BIM

Former research has put forward several success factors for the implementation of BIM in the infrastructure construction sector. These factors range from management commitment to data validation. A literature review on the important factors that lead to the better establishment of this system in organizations introduces the factors in Table 1. Two types of factors affect the implementation of the BIM system in organizations, which include (1) technical factors such as predictive design analysis and simulations, as well as (2) managerial factors such as effective leadership.

Table 1: The main contributions of the BIM system

Success factors for BIM implementation		Dimensions	References
Technical	Accurate 3D visualization of design	3D	[14]
	Appropriate information technology infrastructure	1D to 10D	[15]
	Consistency of design across disciplines	1D to 10D	[16]
	Predictive analysis of the performance of a facility	7D	[14, 17]
	Conducting the thermal energy analysis of the facility	6D	[18]
	Predictive analysis of the environmental impacts	6D and 7D	[19]
	Synchronization of procurement with design specifications	5D to 10D	[14]
	Qualified technical staff to establish BIM	1D to 10D	[17, 20]
	Validation of the model	3D	[19]
	Reliability of the input data	1D to 10D	[21]
Managerial	Supportive organizational culture	1D to 10D	[22]
	Information and knowledge exchange	1D to 10D	[23]
	Stakeholder engagement and collaboration	1D to 10D	[24]
	Clear policy and objectives in BIM	1D to 10D	[25, 26]
	Effective leadership of the BIM implementation	1D to 10D	[17]
	Allocation of budget to BIM	1D to 10D	[26, 27]

2.3 Information systems needed to implement BIM

Implementation of the BIM system requires prerequisite information systems and software to be in place. Previous studies have examined such prerequisites and discussed their link to BIM dimensions. Project information systems provide a platform for collecting and utilizing performance information, earned value, approved change requests, non-compliance reports, and work inspection requests. Such a system integrates time, cost, scope, and quality information and can provide the BIM system with data for linking them with a 3D model [10]. For example, 4D and 5D BIM need the project schedule and cost baseline to be linked to the elements of the design. Project information systems can supply the necessary information for undertaking such analysis. It is suggested to combine AutoCAD and Microsoft Project for the development of a consolidated database that allows for construction process simulation before commencing the construction work [28]. A thorough analysis of the project cost estimates with regard to design features can significantly help to improve estimates and identify errors. The existence of financial information systems (FIS) and their link to the BIM facilitates the transmission of important financial information such as cash flow forecast to be simulated for the whole timeline of a construction project. The existence of FIS and its link to BIM gives clues to estimators to verify cost estimates and optimize quantity take-offs, which is the basis for better long-term financial planning.

Construction projects have plenty of diverse documents such as contracts, engineering drawings, marking plans, assembly plans, and progress reports, which need to be stored in a secure database. BIM needs to be linked to such databases to share with stakeholders and use the information for data visualization. Document management systems (DMS) allow predesignated users to store or retrieve project documents from a shared database. The existence of DMS and its interoperation with BIM contributes to centrally controlling project documents in a project. Another important system to be in place and link to the BIM system is the safety information system. Incorporating safety information into the visualization of construction models gives insight into hazards and corresponding controls to be considered early in the design phase of an infrastructure construction project. Linking the safety information system and BIM enables undertaking hazard risk analysis and better safety planning [11]. The establishment of the 8D dimension requires that an information system of safety inspection records, safety training, incidents, and injuries be established to store the safety-related information and import them into the BIM system for visualization and analysis [29]. The establishment of safety information systems and provision of necessary safety performance data enables real-time safety reporting, as well as hazard risk analysis, regarding the design features of a facility.

2.4 Previous research on BIM Implementation

Implementation of the Building Information Modelling system is quite challenging considering the multiple modules of this system and their interoperation. A recent study examined the implementation of this system in two case studies including an urban regeneration project, and a healthcare project. The focus of this study was on the disconnections between organizational and project level BIM implementation to usefully inform implementation strategy development. It was found that the implementation of the BIM system improved consultation meetings with the client leading to improvements in design quality. Besides, 3D visualization of the design and project parameters provided an in-depth understanding of the facility. However, it is recommended that more effective implementation strategies need to be in place to take maximum advantage of this system both at the organizational and project level. According to this case study, the organizational-level BIM training system failed to support the project-level requirements in new technology adoption [30]. In another study, the issues related to the implementation of the BIM system in the construction industry were examined. The researchers studied global implementation strategies and asserted the importance of coordinated government support and leadership, the development of national and global BIM standards, legal protocols, BIM certification, and BIM education and training [31].

Other studies also attempted to examine barriers to implementation strategies. Zhou et al. [32] examined the barriers in China and found that global strategies should address insufficient government leadership, organizational issues, legal issues, high cost of application, resistance to change of thinking mode and insufficient external motivation. In another study, these barriers were confirmed and it was asserted that strategies should be adopted to deal with skilled personnel shortage [33]. Furthermore, Ma et al. [34] compared BIM implementation strategies in different countries (China, Singapore, Turkey, and Nigeria) and suggested strategies including clearly defined plans and objectives, training and consultancy, organizational leadership and support, financial support, BIM infrastructure, collaborative design, capabilities and skills, access to information and technical conditions, interoperability of engineering data, clients' advocation, and early adoption of BIM regulation. While most of the previous studies have examined the global implementation strategies, the current study concentrates on the company-level strategies which need to be taken into account for a successful implementation so that both the organization and stakeholders can benefit from its positive outcomes in relation to the process of the design and construction. Besides, a more specific focus on the infrastructure construction sector would benefit the body of knowledge since this sector deal with a high level of design and construction complexities [35]. It is important to differentiate between infrastructure delivery, infrastructure construction, and infrastructure management. The current study focuses on infrastructure which should be closely coordinated with the design to deliver a sustainable facility. Thus, the underlying research question is to identify company-level strategies for the implementation of the BIM system in infrastructure construction projects.

3. Methods

The current research is based upon the theoretical discussions in the literature and includes experts' viewpoints on the contribution of BIM in infrastructure construction. The target population includes project management professionals working in principal construction contracting enterprises in Australia. The case study approach allows an in-depth examination of a situation to delve into details of processes and associated outcomes [36]. As a result of a case study in an infrastructure construction project, six practitioners provided their comments on this application of the BIM system. The suggestions from each expert were documented and reviewed so that an overview of the experts' viewpoints can be provided in the paper. Purposive sampling was conducted to ensure that the selected experts have at least five years of relevant experience in the industry. The selected participants worked in project management positions in the case study organization and had job tenure in delivering infrastructure projects [30].

The experts who participated in this study had more than five years of work experience. Six participants with respectively 21, 18, 16, 12, and eight years of work experience provided their insights about BIM implementation. Their positions in the infrastructure project include project manager, assistant project manager, project planners, information technology officer, and designer (two participants). According to the literature, there is no one-size-fits-all threshold to reach data saturation and it is suggested to continue data collection until no new data is obtained [37]. Applying this principle, the saturation point was reached in the sixth interview. The repetitiveness of the comments of participants compared with those obtained from previous interviews was the trigger to stop the data collection. The questions which were asked from the participants include: (1) what is the main contribution of each BIM dimension to infrastructure construction projects? (2) what are the technical strategies for the effective implementation of the BIM system in infrastructure construction projects? and (3) what are the technical strategies for the effective implementation of the BIM system in infrastructure construction projects?

Interviews with the participants were conducted in 30 minutes and their suggestions on the contribution of the BIM system and effective strategies for its implementation in the infrastructure construction sector were obtained. The semi-structured interviews were transcribed and the key suggestions were documented. A thematic analysis of these descriptive suggestions was conducted as a systematic qualitative methodology that involves an inductive data-driven approach for synthesizing and conceptualizing data [38]. This integrative approach brings related ideas together to form the main theoretical feature of a phenomenon. The open coding method was applied to find meaningful themes in experts' suggestions. The results of the interviews were sent to the participants to confirm and improve the outcomes. This validation process helped to improve the validity and rigour of the case study results. As a result of this process, their perspective on (1) the contribution of the BIM system to better infrastructure construction, as well as, (2) the managerial/technical strategies for a more effective implementation were obtained. The results of these parts of the study have been explained in detail in the next section. The research process is outlined in Figure 2.

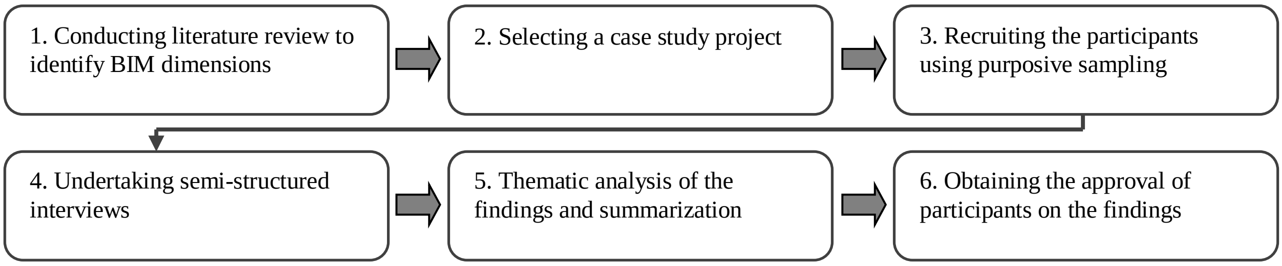

Figure 2: The overview of the research process

4. Results

4.1. The contribution of the BIM dimensions to infrastructure construction projects

The first part of the results is to answer how each dimension of the BIM system can improve the process and outcomes of infrastructure construction projects. Although BIM has application to both the construction and management of infrastructure, the present study focused on the construction stage by undertaking a case study of an infrastructure construction project. As a result of the thematic analysis of interviews regarding the first question (as explained in the methods section), the main contribution of each BIM dimension to infrastructure construction projects was identified. Then, in the next section, the results of analysing data obtained from participants' responses to the second and third interview questions about potential implementation strategies are presented.

1D BIM contributes to (1) providing a historical archive of project information and the evolution of drawings over time, (2) sharing information on project requirements and contracts among stakeholders, (3) keeping the record of the last version of documents for further changes and modifications in details, and (4) clarifying the scope of work and requirements that need to be fulfilled at each phase of an infrastructure construction project. 2D BIM enables the basic modelling of a project through CAD drawings. This aspect of BIM (1) improves the flexibility of the design process by enabling designers to change and update the layout easier than paper-based design, (2) save time in producing and keeping a digital record of drawings compare with manual design, (3) eliminates most of the errors which may occur as a result of calculations, and (4) reduce the cost of design compared with manual drawings.

3D BIM as an important aspect of the BIM system helps to (1) minimize design errors and detect clashes more effective than 2D CAD by visualizing three dimensions, (2) incorporate more design-related information from the perspective of each discipline to improve the 3D model from all perspectives, (3) improve the interdisciplinary collaboration of designers and subject-matter experts, (4) attain higher visibility of the design, and (5) convey the scope and details of a building or facility more effectively. 4D BIM is recently used in the construction industry for better error detection and effective task scheduling. The integration of time and 3D allows (1) more efficient sequencing of the construction process, (2) adjustment of a project activity network to follow a reasonable building methodology, (3) modification of the duration as well as the of the lead/lag between tasks by using schedule animation tools, and (4) keeping track of tasks and their progression. Besides, (5) the risk of project delays due to conflicts of execution with the design documents and plans are anticipated and controlled in advance.

5D BIM as an important dimension of the BIM system contributes to (1) accurate estimation of the cost associated with the construction activities, (2) optimization of cash flows and avoiding project liquidity by adjusting the expenditures, (3) development of more cost-effective infrastructure, (4) automatic generation of quantity take-offs, (5) saving time in the cost forecasting process, (6) reduction of the budgetary offshoot, and (7) real-time visualized analysis of changes in project costs. 6D BIM added the energy considerations to 5D and provides multi-platform access to the building information from the perspective of energy consumption. This dimension allows for (1) energy optimization in the operation of a facility, (2) adopting better operational strategies for optimal performance of a facility, (3) incorporating energy estimates at initial stages of design, and (4) building an energy-efficient facility with minimal cost of operation over time.

The 7D BIM aspect contributes to (1) a more effective decision making related to the operation and maintenance of a facility, (2) an impact assessment of design-related decisions on operational aspects of a facility, (3) more rigorous planning for easy replacement and repairs of equipment in a facility, (4) optimized asset management, and (5) Streamlined maintenance process for clients. 8D BIM considers safety in modelling the facility. The integration of safety into the BIM model enables (1) the establishment of emergency plans, (2) the prevention of security issues, (3) implementation of the occupational health and safety standards throughout the stages of delivery and operations, and (4) decrease risks of accidents and safety hazards.

As a prospective aspect of BIM, the ninth dimension incorporates lean construction and contributes to (1) improving the allocation of resources, (2) enhancing the productivity of construction processes, (3) enhancing the structural integrity of the facility, and (4) optimizing the building design and construction methods towards minimizing waste of materials. Full industrialization is the ultimate goal of BIM in the future, which is conceptualized in the 10D BIM framework. This theoretical dimension represents full industrialization in the construction sector that contributes to (1) automating engineering planning and control procedures, (2) applying virtual reality elements in construction processes, (3) real-time monitoring and controlling the operations, and (4) systematically drive continuous improvement of processes.

An analysis of these aspects in terms of their similarities and differences revealed that the contribution of BIM to infrastructure construction can be translated into three groups including (1) integrity and automation, (2) collaboration, and (3) optimization. Table 2 presents the result of analysing the experts' suggestions in these three categories. Participants also asserted that some dimensions of the BIM system are more important during the design and construction of a facility. It was revealed that 4D and 5D BIM are more beneficial to the construction stages due to visualizing the progression of time and cost. Furthermore, 8D BIM significantly contributes to improving safety outcomes by real-time safety reporting and information sharing that constitute a basis for collaborative safety management on construction sites. 9D BIM is also another key dimension of this system that is quite important throughout the project lifecycle by minimizing waste and optimizing resource allocation.

Table 2: The main contributions of the BIM system to infrastructure construction projects

BIM dimension	Contributions		
	(1) Integrity and automation	(2) Collaboration	(3) Optimization
1D BIM	• Providing a digital archive of all project documents • Managing further changes and modifications to documents	• Sharing information on project requirements • Clarifying the scope of work	
2D BIM	• Easier update in the layout • Keeping the record of all versions of drawings		• Error-free design calculations • Reduce the cost of design
3D BIM	• Higher visibility of all aspects	• Multi-discipline feedback on the design • Convey the scope effectively	• Detect clashes
4D BIM	• Adjust the duration and the lead/lag time • Keeping track of tasks	• Prevent conflicts of execution with plans	• More efficient sequencing of tasks • Reflect a more reasonable building methodology
5D BIM	• Automatic generation of quantity take-offs	• Accurate estimation of the cost through the collaboration of design and estimating team	• Prevent project liquidity • Develop cost-effective infrastructure • Reduce budgetary offshoot
6D BIM	• Incorporate energy estimates in the design	• Better operational strategies in relation to all disciplines	• Energy optimization in the operation stage • Building an energy-efficient facility • Minimal cost of operation
7D BIM	• Analyse the impact of design on the operation • Streamlined maintenance process	• Effective collaborative planning of replacement and repairs	• Optimized asset management • Effective operation and maintenance
8D BIM	• Implementing occupational health and safety standards	• Establishment of emergency plans from the perspective of involved teams	• Decrease risks of accidents • Prevention of security issues
9D BIM	• Enhance the structural integrity of the facility	• Enhance the productivity of construction processes in a collaborative way	• Improve resource allocation • Minimize waste of materials
10D BIM	• Apply virtual reality elements • Real-time monitoring and control of all tasks • Automate engineering planning and control		• Continuous improvement of processes

4.2. Technical strategies for effective implementation of the BIM system

Build a strong BIM technical team: The first and foremost necessity for successful implementation of the BIM system in large multi-discipline infrastructure projects is to be equipped with the required technical expertise among the implementation team. A dedicated team with a high level of BIM technical competencies can bring their expertise and experience to minimize the risk of system errors and failure after implementation. This suggested strategy also confirms the finding of the literature on the role of trained and expert staff in better BIM establishment [17, 20]. Technical competencies have been asserted in previous studies as an important element that facilitates the implementation of BIM. Profound technical knowledge of the BIM implementation team benefits the organization in selecting the correct configuration of each module and aligning them with the requirements and needs of projects [34].

Reinforce information technology infrastructure: An important strategy to improve the information technology (IT) infrastructure necessary as a building block for the establishment of the BIM system. Linking all subsystems and technologies within an organization would benefit better BIM implementation, which enables synchronization of the design, procurement, and construction [14]. Investment in information technology infrastructure helps an organization provide tools and gadgets facilitating the flow of information throughout an organization, as well as between an organization and its stakeholders. Comprehensive information technology needs assessment before starting the BIM implementation would be useful in identifying gaps in IT infrastructure and potential issues which may hinder the implementation process. Adequate information systems, monitoring dashboards, scheduling and estimating software are to be supplied and well established throughout a project [39].

Conduct pilot test: Starting the setup process on a small scale assists the implementation team to capture early feedback and address technical issues in workflows and tools. The implementation team closely tests the process and outcomes of the BIM in the pilot implementation stage to avoid the recurrence of issues on a large scale which would impose higher operational costs. Pilot setup is also acknowledged as a key strategy in the implementation of information systems in general [40], which is also applicable to the implementation of the BIM system. Pilot testing improves the system reliability by detecting and rectifying errors in the modules of the system before the implementation in full scale. The interaction of the BIM system with enterprise systems and databases is also tested during the pilot stage so that the implementation team can ensure the adequacy and quality of input data for 3D simulation and visualization.

Introduce mobile applications: Regarding the ever-increasing use of mobile applications in the construction industry, they are becoming more and more prevalent among companies due to their accessibility and convenience for users [41]. They provide effective tools for more convenient and instant access of decision-makers to the BIM system. Such tools improve agility in the BIM system and, therefore, should be considered early in the design stage by the implementation team as a robust tool. Nourbakhsh et al. [42] developed a mobile application prototype for on-site information management in the construction industry. They demonstrated that mobile applications can be used as a user-friendly tool to manage on-site information generated by involved parties in the construction process. Participants of this study explained that developing simple and functional mobile applications enables instant transmission of information and more convenient access of all the users of the BIM system.

4.3. Managerial strategies for effective implementation of the BIM system

Develop implementation roadmap: The implementation plan is part of establishing BIM in companies [43]. However, a more comprehensive plan is needed to map out all phases of future development and the approach for implementing them. Roadmaps outline not only the establishment of subsystems but also should include future upgrading and evolution of the BIM system to achieve the ultimate target of this system, which is total industrialization of the construction sector. The development of such a roadmap clarify the main stages for the implementation of each dimension of the BIM system. Project leaders may decide to start with limited modules of the BIM system and gradually expand the scope of this system to mechanize processes [44]. System requirements and required infrastructure for making a transition between implementation phases are of crucial significance to prevent errors and provide resources necessary for the implementation of each BIM dimension.

Identify and engage stakeholders: The establishment of any management mechanisms without adequate consideration of stakeholders becomes a challenging task. A complex network of stakeholders may be affected or affect BIM outcomes in large infrastructure projects and even during the commissioning and operations stages. Such stakeholders and their expectations should be identified to seek their buy-in and approval. It is an effective strategy to reduce the risk of low participation and organizational resistance. Although previous research has acknowledged stakeholder engagement as an important success factor of the BIM system, this study asserted that it is vital to focus on identifying all key stakeholders and analysing their interests before deciding on appropriate engagement strategies [24].

Assign dedicated monitoring and coordination team: Previous studies pointed to the importance of trained experts for the proper implementation of the BIM system. While the experts who participated in this research suggested that a dedicated team should be allocated to keep track of the implementation process and undertake the coordination of modules and subsystems in collaboration with the core BIM implementation team. This aspect of implementation has not been mentioned in previous studies and needs to be considered for a more integrated implementation of all sub-systems. BIM has the capacity to reduce clashes through 3D design coordination if the data is supplied timely and correctly [45]. Dedicating a team to ensure appropriate information exchange and coordination of modules would help to establish the inter-module and inter-system links with a minimum risk of misinterpretations and data inaccuracy (Figure 3).

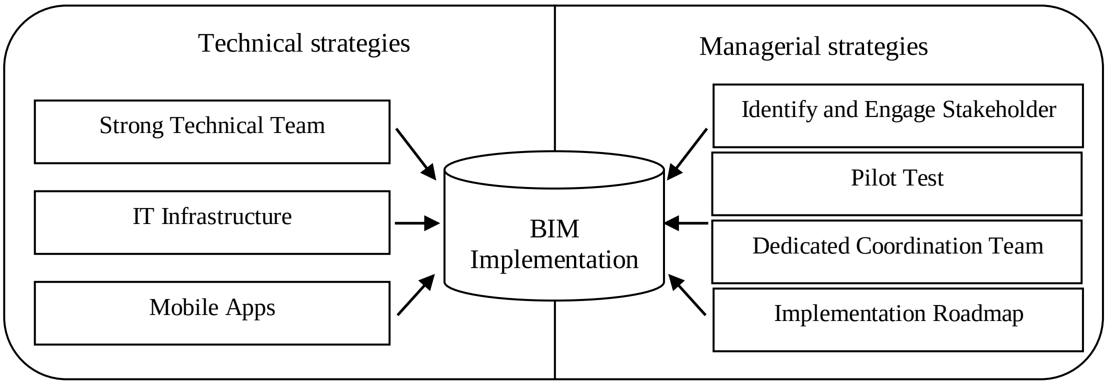

Figure 3: Technical and managerial strategies for more effective implementation of the BIM system

5. Discussion

5.1. The implications of the study

From the theoretical perspective, the present study contributes to a better understanding of the BIM dimensions and their contribution to better infrastructure construction. The three categories of BIM contributions are interrelated and form a value chain leading to better outcomes from the implementation of this information system. First, the basic and underpinning contribution of BIM as a robust information system is to digitalize documents and mechanize processes as a basis for better management of records and control of configurations. The specifications are stored in a secure database and can be used for further reference or change analysis. This category of BIM contributions refers to managing the interfaces between different subsystems concerning all involved teams such as architectural designers, engineering designers, health and safety experts, waste management practitioners, estimators, energy analysts, and project planners. This finding confirms this view that BIM plays a prominent role in the visualization [1] and acts as an integrating platform for other design, construction, operation, and maintenance systems [16].

Second, all teams of subject-matter specialists can collaborate effectively and share their knowledge to accomplish their tasks more productively. Instant sharing of information improves the agility of interdisciplinary decisions and even integrates design-to-demolition operations. Tasks and action plans are synchronized, which pave the way for the coordination of designers, planners, and contractors during the delivery stages. The subsystems interoperate seamlessly based on integrated data to nurture the synergy of subject-matter professionals. As asserted in previous studies, BIM is a means of communication among stakeholders to decrease the risk of miscommunication or conflicts between different aspects of a facility [24].

Third, collaboration encourages innovation and better problem solving as a result of encouraging experts in bringing new ideas and share their best practices. The effective use of visualization and analytical tools coupled with this coordination leads to higher levels of productivity in resources. BIM tools can be applied to analyse inputs from different disciplines to detect errors in design and plans. Major risks of conflicts are identified and control so that as a prerequisite of smooth construction. This aspect of contribution posits that optimization of the energy consumption [8], design features [6], delivery schedule [9], and sustainability characteristics [18] can be achieved through proper implementation and application of BIM in the construction industry (Figure 4).

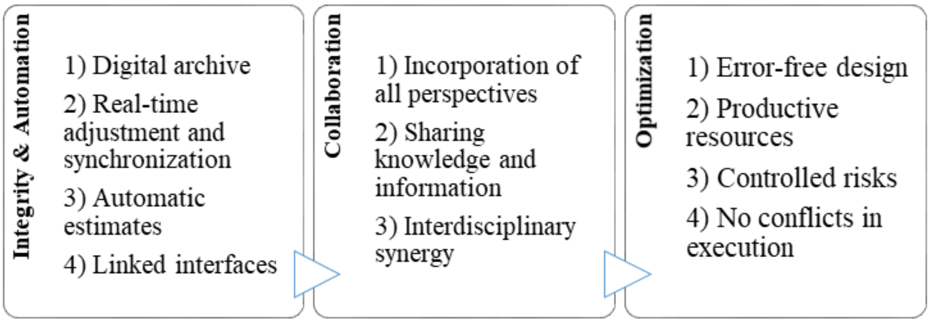

Figure 4: The value chain of BIM

As the empirical implication, the current study reflected on the suggestions of industry experts and introduced technical and managerial strategies for better implementation of the BIM system in the infrastructure development sector. The category of technical strategies aims to enhance the effective establishment of tools, plugins, platforms, and modules to ensure interoperability and synchronization of all components of the BIM system. On the other hand, the managerial strategies focus on enablers in an organizational context that should be properly leveraged to minimize resistance to change and engage stakeholders for a smooth implementation of the BIM section in infrastructure construction projects.

5.2. The limitations and future research

This work is limited due to its theoretical approach reflecting on experts' opinions, indicating that there is a need to validate the outcomes through further empirical research. BIM systems have a variety of applications and can be applied in contexts other than the infrastructure sector. We encourage future studies to undertake a survey or case study analysis to examine the application, benefits, and impacts of the BIM system. This study is also limited since it adopted a universal perspective and discussed all ten aspects of BIM. Thus, future studies can elaborate on a specific dimension of BIM and explore its application and requirements. Another line of potential research on the topic would be to develop a structural equation model of success factors for the BIM implementation. In this regard, the success factors which were synthesized from the literature can be further developed, validated, and tested using statistical analysis tools.

6. Conclusion

The purpose of the present paper was to provide insight into the dimensions of the Building Information Modelling system from a theoretical perspective and introduce effective strategies for their implementation. The view of experts in a case study was reflected to highlight the contributions of the BIM system and introduce effective strategies to implement it. This study posited that there are ten main dimensions of the BIM system that are complementary to each other and map out the evolution of this approach over recent years, which is still under development. These dimensions showed that BIM simulates important technical aspects of a facility from the perspective of three geometrical dimensions of a building. These aspects include time (4D), cost (5D), energy (6D), sustainability (7D), safety (8D), lean construction (9D), and industrialized construction (10D). The integration of the technical specifications of a facility through the lenses of these domains enables adjusting designs and plans to optimize the ultimate project deliverable. It was found that 4D, 5D, 8D, and 9D BIM are more important during the design and construction stages.

The thematic analysis of interviews indicated that three categories represent the contribution of the BIM system to infrastructure construction. This system provides a basis for the automation of workflows. Achieving integrity at the process level ensures that process assets such as procedures and routines are in order and in a complete form to enable a smooth flow of information and decisions across the departments and technical teams. Establishment of tools and information systems under the umbrella of a centralized platform help to automate procedures and minimize the delays and waiting time in different project tasks. It was found that integrity and automation are prerequisites of a collaborative approach in infrastructure construction since without such integration of interfaces the technical specifications of a facility are not being fully captured to be considered in all stages of the engineering design. In light of integrity as well as collaboration, construction practices and outcomes are optimized and errors are eliminated. As another part of the findings, the BIM system can be implemented more effectively by focusing on technical and managerial strategies. While technical strategies improve the foundation and components of such a system, the managerial strategies target resources and support that should be sought towards facilitating the implementation process.

References

[1] T. Jadhav, "Building Information Modeling for Heating, Ventilation and Air Conditioning Application," *International Journal of Architecture, Engineering and Construction,* vol. 8, no. 4, 2019.
[2] A. N. Hasan and S. M. Rasheed, "The benefits of and challenges to implement 5D BIM in construction industry," *Civil Engineering Journal,* vol. 5, no. 2, p. 412, 2019.
[3] I. Kamardeen, "8D BIM modelling tool for accident prevention through design," in *26th annual ARCOM conference*, 2010, vol. 1: Association of Researchers in Construction Management Leeds, pp. 281-289.
[4] I. O. Onungwa and N. Uduma-Olugu, "Building information modelling and collaboration in the Nigerian construction industry," *Journal of Construction Business and Management,* vol. 1, no. 2, pp. 1-10, 2017.
[5] F. H. Abanda, C. Vidalakis, A. H. Oti, and J. H. Tah, "A critical analysis of Building Information Modelling systems used in construction projects," *Advances in Engineering Software,* vol. 90, pp. 183-201, 2015.
[6] J. Rogers, H.-Y. Chong, and C. Preece, "Adoption of building information modelling technology (BIM)," *Engineering, Construction and Architectural Management,* vol. 22, no. 4, 2015.
[7] M. Alhusban, M. Danso-Amoako, and M. Gaterell, "Procurement route and Building Information Modelling (BIM) implementation effect on sustainable higher education refurbishment projects," in *Building Information Modelling, Building Performance, Design and Smart Construction*: Springer, 2017, pp. 105-112.
[8] F. J. Montiel-Santiago, M. J. Hermoso-Orzáez, and J. Terrados-Cepeda, "Sustainability and Energy Efficiency: BIM 6D. Study of the BIM Methodology Applied to Hospital Buildings. Value of Interior Lighting and Daylight in Energy Simulation," *Sustainability,* vol. 12, no. 14, p. 5731, 2020.
[9] K. d. Wong and Q. Fan, "Building information modelling (BIM) for sustainable building design," *Facilities,* vol. 31, no. 3/4, pp. 138-157, 2013.

[10] S. Shirowzhan, W. Tan, and S. M. Sepasgozar, "Digital twin and CyberGIS for improving connectivity and measuring the impact of infrastructure construction planning in smart cities," ISPRS International Journal of Geo-Information, vol. 9, issue. 4, pp. 240, 2020.
[11] F. Harris, R. McCaffer, A. Baldwin, and F. Edum-Fotwe, *Modern construction management*. John Wiley & Sons, 2021.
[12] S. B. A. Guetat and S. B. D. Dakhli, "A multi-layered software architecture model for building software solutions in an urbanized information system," *International Journal of Information Systems and Project Management*, vol. 1, no. 1, pp. 19-34, 2013.
[13] R. Morlhon, R. Pellerin, and M. Bourgault, "Defining Building Information Modeling implementation activities based on capability maturity evaluation: a theoretical model," *International Journal of Information Systems and Project Management*, vol. 3, no. 1, pp. 51-65, 2015.
[14] M. Antwi-Afari, H. Li, E. Pärn, and D. Edwards, "Critical success factors for implementing building information modelling (BIM): A longitudinal review," *Automation in construction*, vol. 91, pp. 100-110, 2018.
[15] A. Hanna, F. Boodai, and M. El Asmar, "State of practice of building information modeling in mechanical and electrical construction industries," *Journal of Construction Engineering and Management*, vol. 139, no. 10, p. 04013009, 2013.
[16] C. M. Eastman, C. Eastman, P. Teicholz, R. Sacks, and K. Liston, *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons, 2011.
[17] S. Lee, J. Yu, and D. Jeong, "BIM acceptance model in construction organizations," *Journal of Management in Engineering*, vol. 31, no. 3, p. 04014048, 2015.
[18] R. Sebastian and L. van Berlo, "Tool for benchmarking BIM performance of design, engineering and construction firms in the Netherlands," *Architectural Engineering and Design Management.*, vol. 6, no. 4, pp. 254-263, 2010.
[19] S. Azhar, "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry," *Leadership and management in engineering*, vol. 11, no. 3, pp. 241-252, 2011.
[20] B. Succar, W. Sher, and A. Williams, "An integrated approach to BIM competency assessment, acquisition and application," *Automation in construction*, vol. 35, pp. 174-189, 2013.
[21] J. Boktor, A. Hanna, and C. C. Menassa, "State of practice of building information modeling in the mechanical construction industry," *Journal of Management in Engineering*, vol. 30, no. 1, pp. 78-85, 2014.
[22] F. Khosrowshahi and Y. Arayici, "Roadmap for implementation of BIM in the UK construction industry," *Engineering, Construction and Architectural Management*, vol. 19, no. 6, pp. 610-635, 2012.
[23] Ş. T. Pektaş and M. Pultar, "Modelling detailed information flows in building design with the parameter-based design structure matrix," *Design Studies*, vol. 27, no. 1, pp. 99-122, 2006.
[24] Y. Lu, Y. Li, M. Skibniewski, Z. Wu, R. Wang, and Y. Le, "Information and communication technology applications in architecture, engineering, and construction organizations: A 15-year review," *Journal of Management in Engineering*, vol. 31, no. 1, p. A4014010, 2015.
[25] B. Becerik-Gerber and S. Rice, "The perceived value of building information modeling in the US building industry," *Journal of Information Technology in Construction (ITcon)*, vol. 15, no. 15, pp. 185-201, 2010.
[26] B. Ozorhon and U. Karahan, "Critical success factors of building information modeling implementation," *Journal of Management in Engineering*, vol. 33, no. 3, p. 04016054, 2017.
[27] J. Won, G. Lee, C. Dossick, and J. Messner, "Where to focus for successful adoption of building information modeling within organization," *Journal of Construction Engineering and Management*, vol. 139, no. 11, p. 04013014, 2013.
[28] C. H. Caldas, L. Soibelman, and L. Gasser, "Methodology for the integration of project documents in model-based information systems," *Journal of Computing in Civil Engineering*, vol. 19, no. 1, pp. 25-33, 2005.
[29] D.-G. Lee, J.-Y. Park, and S.-H. Song, "BIM-based construction information management framework for site information management," *Advances in Civil Engineering*, vol. 2018, 2018.
[30] R. M. Dowsett and C. F. Harty, "Assessing the implementation of BIM–an information systems approach," *Construction Management and Economics*, vol. 37, no. 10, pp. 551-566, 2019.
[31] P. Smith, "BIM implementation–global strategies," *Procedia Engineering*, vol. 85, pp. 482-492, 2014.

[32] Y. Zhou, Y. Yang, and J.-B. Yang, "Barriers to BIM implementation strategies in China," *Engineering, Construction and Architectural Management,* vol. 26, no. 3, pp. 554-574, 2019.
[33] S. Liu, B. Xie, L. Tivendal, and C. Liu, "Critical barriers to BIM implementation in the AEC industry," *International Journal of Marketing Studies,* vol. 7, no. 6, p. 162, 2015.
[34] X. Ma, A. P. Chan, Y. Li, B. Zhang, and F. Xiong, "Critical strategies for enhancing BIM implementation in AEC projects: perspectives from Chinese practitioners," *Journal of Construction Engineering and Management,* vol. 146, no. 2, p. 05019019, 2020.
[35] B. Fanning, C. M. Clevenger, M. E. Ozbek, and H. Mahmoud, "Implementing BIM on infrastructure: Comparison of two bridge construction projects," *Practice periodical on structural design and construction,* vol. 20, no. 4, p. 04014044, 2015.
[36] J. Gerring, "What is a case study and what is it good for?," *American political science review,* vol. 98, no. 2, pp. 341-354, 2004.
[37] G. Guest, A. Bunce, and L. Johnson, "How many interviews are enough? An experiment with data saturation and variability," *Field Methods,* vol. 18, no. 1, pp. 59-82, 2006.
[38] N. King and J. Brooks, "Thematic analysis in organisational research," ed: SAGE Publishing Thousand Oaks, CA, 2018.
[39] J. van Besouw and T. Bond-Barnard, "Smart Project Management Information Systems (SPMIS) for Engineering Projects–Project Performance Monitoring & Reporting," *International Journal of Information Systems and Project Management*, vol. 9, no. 1, pp. 78-97, 2021.
[40] M. Hertzum, J. P. Bansler, E. C. Havn, and J. Simonsen, "Pilot implementation: Learning from field tests in IS development," *Communications of the Association for Information Systems,* vol. 30, no. 1, p. 20, 2012.
[41] T. Liu, A. Mathrani, and J. Mbachu, "Benefits and barriers in uptake of mobile apps in New Zealand construction industry: What top and middle management perceive," *Facilities,* vol. 37, no. 5/6, pp. 254-265, 2019.
[42] M. Nourbakhsh, R. M. Zin, J. Irizarry, S. Zolfagharian, and M. Gheisari, "Mobile application prototype for on-site information management in construction industry," *Engineering, construction and architectural management,* vol. 19, no. 5, pp. 474-494, 2012.
[43] E. Hochscheid and G. Halin, "Micro BIM adoption in design firms: Guidelines for doing a BIM implementation plan," in *Creative Construction Conference Proceeding,* 2019: Budapest University of Technology and Economics, pp. 864-871.
[44] X. Ma, F. Xiong, T. O. Olawumi, N. Dong, and A. P. Chan, "Conceptual framework and roadmap approach for integrating BIM into lifecycle project management," *Journal of Management in Engineering,* vol. 34, no. 6, p. 05018011, 2018.
[45] A. O. Akponeware and Z. A. Adamu, "Clash detection or clash avoidance? An investigation into coordination problems in 3D BIM," *Buildings,* vol. 7, no. 3, p. 75, 2017.

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